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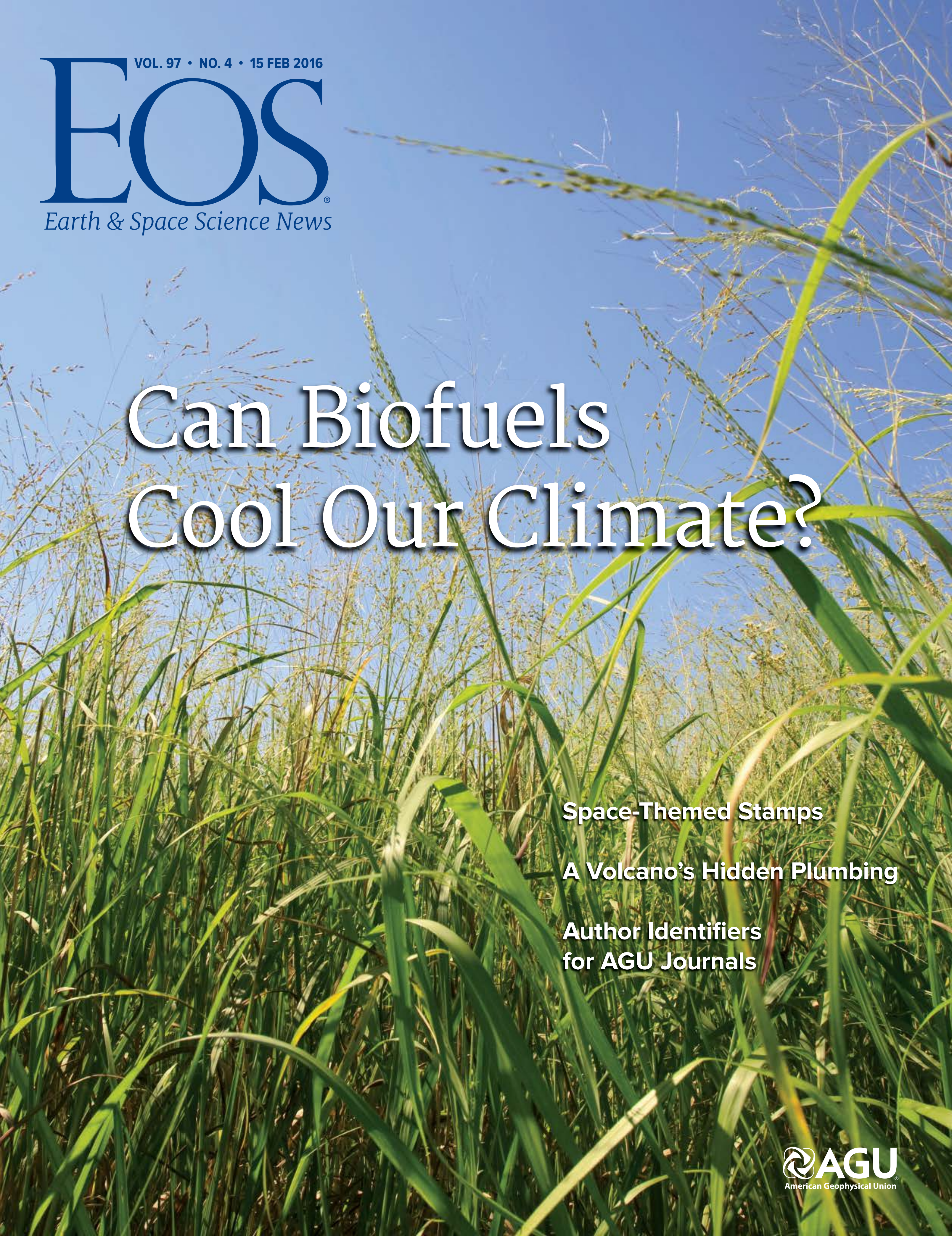
EOS

Earth & Space Science News



Can Biofuels Cool Our Climate?

Space-Themed Stamps

A Volcano's Hidden Plumbing

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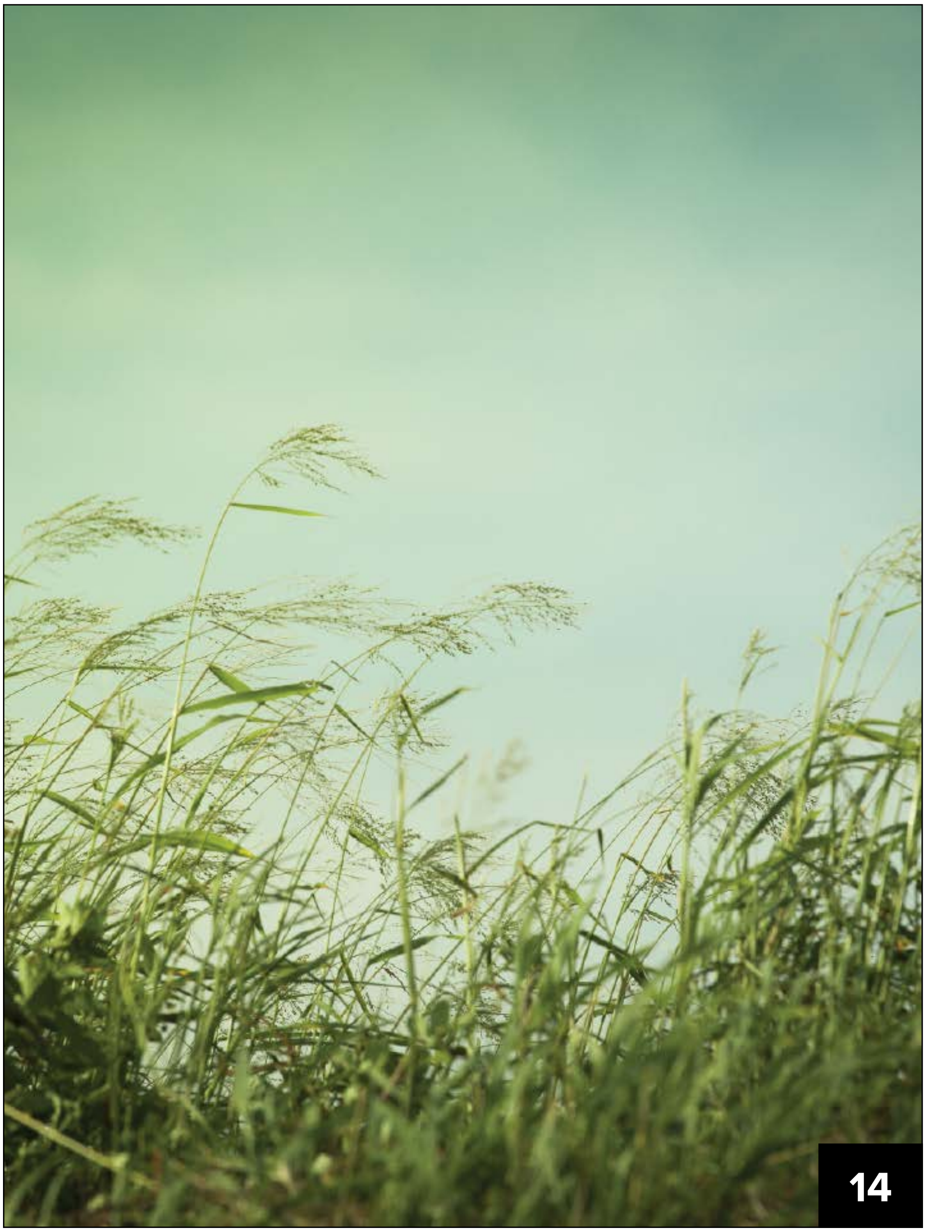

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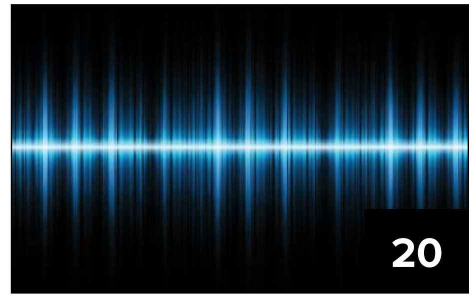

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Bioenergy from perennial grasses offers the benefits of a renewable fuel source without many of the environmental drawbacks of high-maintenance crop sources. Credit: © Design Pics Inc / Alamy Stock Photo

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Vanishing Sea Ice Could Trigger More Arctic Precipitation

Kathryn Hansen, NASA , CC BY-NC 2.0 (http://bit.ly/ccbync2-0)

Decreasing sea ice could cause more precipitation to fall in the Arctic as more Arctic waters are exposed and evaporate into the atmosphere.

Sea ice faces a grim future as global temperatures rise. The warming temperatures melt the ice and force it to retreat further poleward. Images of skinny polar bears often accompany news of sea ice disappearing, but a recent study predicts a less bleak impact of the retreating ice on Arctic weather and precipitation.

The study examined the origins of moisture in the Arctic atmosphere, which falls as rain or snow. The team of researchers, led by Ben Kopec, a graduate student in Dartmouth University's Earth Sciences Department, found that as sea ice retreats, more moisture evaporates from Arctic waters. This moisture then contributes more heavily as a source for precipitation. The researchers predict more atmospheric moisture will lead to an increase in the overall amount of precipitation falling in the Arctic. Their study was published in the *Proceedings of the National Academy of Sciences of the United States of America* (see http://bit.ly/Arctic-precip).

"The overall picture is we think the amount of moisture coming from the Arctic is increasing significantly over [that of] the last two decades, and we expect that to only continue as sea ice is lost," said Kopec.

Kopec and his colleagues examined the isotopic ratios of hydrogen and oxygen to determine where the source waters for Arctic precipitation are located. Water with heavier isotopes would come from the subtropics, the other major source of Arctic moisture, because warmer ocean temperatures there allow that heavier water to break free from the ocean and evaporate.

Isotopes Reveal Moisture Sources

The team investigated data spanning the past 2 decades, and "we saw in that a very strong correlation between decreasing sea ice and decreasing d-excess," said Kopec, referring to a value incorporating the ratios of both hydrogen and oxygen isotopes. A lower d-excess value means that lighter isotopes predominate and that the water most likely originated in the Arctic instead of the subtropics. By this measure, the proportion of water originating in the Arctic increased by 18.2% and 10.8% per 100,000 square kilometers of sea ice lost in the Greenland Sea and the Canadian Arctic, respectively, over the past 2 decades.

Kopec and his colleagues used these numbers to predict how much precipitation will change as sea ice retreats and Arctic-derived moisture increases. They found that precipitation in the Arctic would increase anywhere from about 16% to 28%, depending on how evaporation in the subtropics changes.

Rain or Snow?

The specific form this precipitation takes can further affect the Arctic environment, said Kopec. If it falls as rain, Arctic snow will melt earlier, and the region won't reflect solar radiation away from the surface as effectively. This could compound the warming effects of increasing greenhouse gases. But if more snow falls, the increased albedo of the Arctic would reflect more radiation off the surface and cause regional cooling. "This is a potential mechanism to at least mitigate some of the global warming effects of carbon dioxide at some of these sites," said Kopec.

Changes in Arctic albedo and temperature might also affect storms and precipitation in midlatitude regions. Xiangdong Zhang, a climate scientist at the University of Alaska Fairbanks, presented research at the 2015 AGU Fall Meeting showing how sea ice retreat could decrease storm activity over Eurasia. Warming Arctic waters decrease the temperature gradient from north to south, causing less conver-

sion of energy in those midlatitudes and decreasing storm formation. This could trigger a positive feedback loop between stormless high-pressure systems and colder temperatures over Eurasia. The link between sea ice retreat and decreased storm activity in Asia is noticeable, but researchers haven't discovered much of a link to North America or Europe yet, and the connection between Arctic sea ice and midlatitude storm activity remains under debate.

> "This study deserves a lot of credit for bringing a new approach to the evaluation of Arctic precipitation."

A Way Around Challenges

Kopec's study provides quantitative data on Arctic moisture source waters, and even though it provides only indirect support for subsequent predictions of increasing precipitation, the conclusion is still valid, said John Walsh, an Arctic researcher from the University of Alaska Fairbanks, who was not involved in the study. The atmosphere can only hold so much water before it falls as precipitation, and it is entirely logical that this increase in Arctic-sourced water will cause an increase in snow or rain, said Walsh. Not only are the predictions logical, said Walsh, but they match up with how climate models say Arctic precipitation will change.

The method Kopec and his colleagues used—evaluating moisture contributions using isotopes to predict precipitation—is extremely valuable, said Walsh. "This study deserves a lot of credit for bringing a new approach to the evaluation of Arctic precipitation." Arctic precipitation measurements are notoriously difficult because of cold temperatures and windy conditions blowing precipitation around.

Walsh currently works on climate and meteorological assessment studies in the Arctic and how the environment is changing. He said that this study is important for his own work because it provides a way around the challenges of directly measuring Arctic precipitation. "It is saying there may be more to the story than what the actual gauge measurements are telling us about precipitation," he said, adding that the new study is "a prototype that really does deserve to be extended."

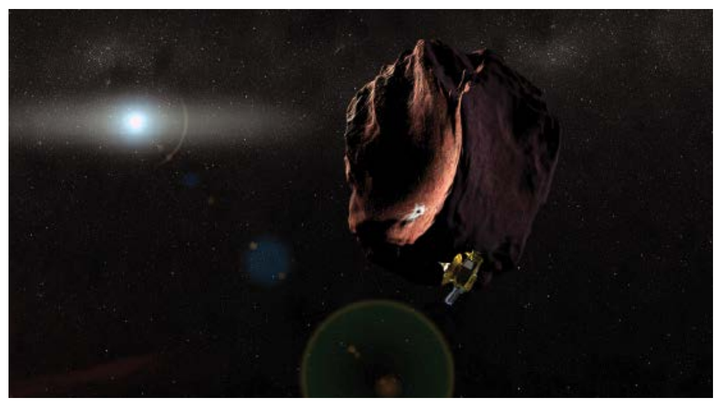
By **Cody Sullivan,** Writer Intern

Next Stop Past Pluto: A World Without Time

Planetary scientist Marc Buie celebrated New Year 2016 with an evening of quiet conversation and board games among family and close friends. However, if all goes according to schedule, Buie and some of those same friends will be ringing in the year 2019 by cheering a cosmic milestone: the first close-up portrait of a denizen of the outer solar system that has likely remained undisturbed and unexplored since the birth of the planets some 4.5 billion years ago.

On 1 January 2019, pending funding approval by NASA, the space agency's New Horizons spacecraft is poised to buzz this frozen, presumably pristine relic, known as 2014 MU69, at a distance of about 6000 kilometers. That's half the distance from which the craft took its historic close-ups of Pluto and its family of moons on 14 July 2015 (see http://bit.ly/Pluto-Up-Close).

When that encounter happens, scientists expect to find a tiny, frozen world locked in time and space in the shrouded and mysterious era and place of its birth. Circumstantial evidence suggests that since it formed, 2014 MU69 has not changed in orbit, composition, or temperature, researchers said. For some 4.5 billion years, it has simply floated, unperturbed, like a perfectly preserved mummy from a creation event that is both chillingly alien and comfortingly personal: the event from which our planet and most everything else that circles our Sun today arose.



NASA/JHUAPL/SwRI/Steve Gribben

In an artist's illustration, the New Horizons spacecraft visits a small ancient world in the Kuiper Belt region of the solar system well beyond the last gas giant planet Neptune. From 6.5 billion kilometers away, the Sun illuminates the scene.

Because 2014 MU69 is so faint, the craft will rely on the powerful lenses of the Hubble Space Telescope to help it find its way. Only during the last 7% or so of its more than 3.5-year journey from Pluto will the New Horizons probe be able to even catch a glimpse of its remote target. On the way or when it gets there, researchers plan a range of investigations, including determining whether volatile substances such as nitrogen and methane are leaking out of the object's interior, whether it has a moon, and how common moons are for objects of its type, New Horizons's mission scientists said.

Other residents of the outer solar system seen up close have been battered about so much since their formation that they cannot take investigators directly back, like 2014 MU69 presumably can, to that early era, in which small bits of gas, dust, and ice coalesced within a swirling disk encircling the young Sun to build the solar system's orbs.

Although both Pluto and 2014 MU69 are members of the Kuiper Belt, a doughnut-shaped reservoir of comets and other icy bodies in the outer solar system, 2014 MU69 occupies a section of the belt that appears to have suffered few disturbances during the billions of years since it arose. Also, unlike Pluto, residents of this region, known as the cold classical belt, have orbits that are nearly circular rather than eccentric and hew close to the plane in which the planets orbit the Sun. These properties suggest that 2014 MU69 and its neighbors have not been stirred up by collisions or gravitational interactions with other bodies, and look pretty much the same as they did when they formed, astronomers say. On the other hand, Pluto and its moons appear to be debris left over when two icy bodies crashed into each other.

Kuiper Belt object 2014 MU69 "harkens back to the building blocks of the solar system," noted Buie, who conducts his research at the Southwest Research Institute (SwRI) in Boulder, Colo. It "may have been modified the least

of anything that has been identified out there. And the less modified it is, the more it retains its primordial fingerprints of the early days of the solar system."

Finding a Keeper

Although scientists had been searching with ground-based telescopes since 2011 for an object that New Horizons could visit in the cold classical belt, they had come up empty-handed and by 2014 were beginning to get anxious. Then, in the early summer of that year, New Horizons scientists got their first survey images from the Hubble Space Telescope, which can see much fainter members of the Kuiper Belt.

Scrutinizing the Hubble data, Buie immediately identified a Kuiper Belt object that might be a candidate for New Horizons.

"Hope you're sitting down," began an email that his New Horizons colleague Alex Parker sent to the rest of the SwRI team on 22 August 2014. Simulations showed that the object, 2014 MU69, had passed every test.

Taking Aim

NASA won't decide until the fall of 2016 if it will fund the 2019 flyby, but scientists couldn't wait for the funding to come through to begin preparing to seize the opportunity; they needed to fire New Horizons's thrusters in the fall of 2015 to nudge the spacecraft onto a path that will place it near 2014 MU69 on New Year's Day 2019. The last of four ignitions was completed on 4 November 2015. Because the cameras on New Horizons won't be able to see the faint object until a few months before the flyby, the mission will rely on additional observations with Hubble to home in on the target.

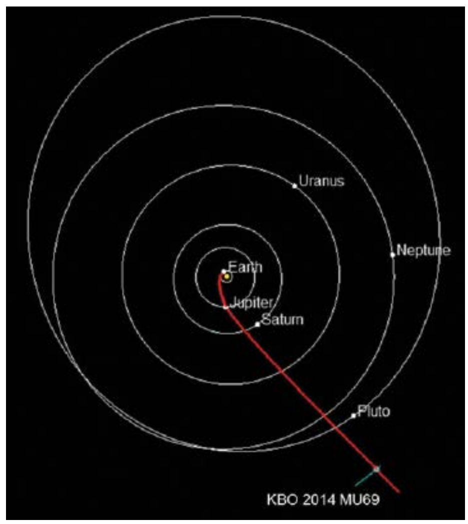
To learn as much as possible from 2014 MU69, scientists are devising a strategy for the eventual flyby. How close should the craft venture to the object? The farther away the spacecraft lies at closest approach, the easier the encounter is to accomplish, but the images won't be as sharp. Get too close, and the speed of the craft as it flies past could smear the images.

"It's risk versus reward," said Buie. Scientists are still debating encounter plans, but it's likely that the craft will pass within 6000 kilometers of 2014 MU69. Observations with Hubble every year until the encounter will be crucial in pinpointing the location and orbit of the Kuiper Belt object, he added.

With only one chance at reaching the remote object, "you have to take an extremely conservative approach to the navigation process," said Buie. "You can't say 'oops, we missed, well, let's do that all over again.'"

Day or Night?

Researchers are also deciding whether to observe 2014 MU69 on the day (sunlit) side or the night side of the object. For scrutinizing Pluto, New Horizons scientists opted to have the craft pass on the night side, even though dayside illumination would have yielded more spectacular images of the surface. The nightside observations enabled the craft to view Pluto during a solar occultation, with the Sun backlighting the dwarf planet as the craft passed through Pluto's shadow. This configuration yielded breathtaking views of the halo of gases in Pluto's atmosphere (see http://bit.ly/Pluto-Atmos).



NASA/JHUAPL/SwRI

Following the trajectory shown in red, the New Horizons spacecraft made a close flyby of Pluto last July and, almost 3 years from now, on New Year's Day 2019, is expected to rendezvous with the small Kuiper Belt object 2014 MU69.

However, 2014 MU69 is a much smaller object and isn't likely to have enough gravity to hold an atmosphere. Scientists therefore plan to observe the object on its day side, with the faraway Sun's feeble light illuminating the icy body.

Although 2014 MU69 may be too small to retain an atmosphere, its size offers its own fascination to scientists. The object spans about one hundredth the diameter of Pluto, while looming some 10 times larger than the Kuiper Belt comets that visit the inner solar system. Because of its midrange girth, 2014 MU69 is "the critical connecting dot between the two types of objects," said Alan Stern of SwRI, who is New Horizons's lead scientist. Observing an intermediate-size object will provide new information on how vastly larger planets assemble from chunks of rock and ice, Stern predicted.

Moon Hunt

Buie and his colleagues look forward to discovering if 2014 MU69 has a moon. Researchers estimate that satellite companions orbit at least 30 percent of Kuiper Belt objects, a number that New Horizons researchers said they hope to refine as the craft observes from afar some 10 to 20 denizens of the belt before and after it homes in on 2014 MU69.

Because the body is so faint, scientists won't be able to discern whether it has a satellite until October 2018, when New Horizons's cameras will first be able to image the body. Finding a moon would force mission scientists to reassess just how pristine 2014 MU69 really is. A moon could signify a collision or 2014 MU69's capture of a passing object, suggesting a busier past for 2014 MU69 than currently suspected.

The gravity of an orbiting moon would enable the team to measure the mass of 2014 MU69. Combined with New Horizons's high-resolution observations of the body's size, the mass measurement would yield the density of 2014 MU69, and therefore its bulk composition—its ratio of ice to rock.

If the density is low—meaning that 2014 MU69 is porous—it could indicate that the Kuiper Belt object was built by an unusually gentle accretion of smaller icy bodies. In that case, the agglomeration would be so loose that it would have left empty spaces between the coalescing fragments. Determining whether the process that built 2014 MU69 was relatively mild or crushingly violent would provide new information on conditions, such as temperature and turbulence, in the outer reaches of the young Sun's primordial, planet-forming disk.

More to Explore

Images and spectra recorded by New Horizons should reveal whether the surface has an ancient crust of water ice or if substances such as nitrogen, carbon dioxide, and methane, which easily evaporate and escape into space, reside on the surface. The presence of these substances would imply that they are continually replenished from the object's interior, propelled outward by some unknown energy source.

"We don't know exactly what this Kuiper Belt object is going to tell us," says Buie, "but we know it's got to be fundamentally important for constraining the early history of the solar system."

After years of planning and searching for an object like 2014 MU69, added Buie's colleague, Parker, New Year's Day 2019 doesn't seem long to wait.

By **Ron Cowen,** Freelance Science Journalist, email: roncowen@msn.com

Novel Vents Built from Talc Found Far from Mid-Ocean Rift

Natural Oceanography Centre

A remotely operated vehicle hangs special high-temperature loggers onto the side of a 5-meter-tall vent chimney at Beebe hydrothermal vent at 4968 meters depth for recovery on the next dive.

With the 1977 observation of ocean-floor fissures spouting scalding water near the Galápagos Islands off the coast of Ecuador, scientists first revealed a world of hydrothermal vents that form where tectonic plates diverge. These vents teem with bizarre marine life and emit sulfurous black smoke from chimney-like mineral deposits. Recently, researchers reported another type of hydrothermal vent with properties unlike any seen before. The finders of this novel sort of vent said the discovery could alter our understanding of geological and chemical processes at the bottom of the sea.

Vent systems typically flank mid-ocean ridges, chains of mountains formed along tectonic plate boundaries where new seafloor forms as the crust pulls apart. But the new vents discovered at the Von Damm Vent Field (VDVF) near the Mid-Cayman Rise in the Caribbean Sea differ in just about every way from familiar "black smokers," according to a recent study published in *Nature Communications* (http://bit.ly/talc-vents).

"The usual way of thinking is that all the heat is on the axis where the magma is and where there's eruptions on the seafloor, and that once you get off it you lose that heat source," said Bill Chadwick, a research professor who studies hydrothermal vents at Oregon State University's Hatfield Marine Science Center in Newport, Oreg., and was not involved with the study. "But this is suggesting that maybe that's not true."

The discovery could alter our understanding of geological and chemical processes at the bottom of the sea.

An Unprecedented Precipitate

The VDVF vents pump out fluids at 215°C from 2-million-year-old crust about 13 kilometers from the axis of the slow-spreading ridge. Although cooler than black smokers, which emit 350°C–400°C fluids, the new vents rank as extremely hot compared to vents previously found so distant from a rift. They draw their heat from a different basement rock than black smokers, acting from ultramafic rock instead of basalt, so the fluid from VDVF vents has a different composition than what's typically found. Instead of thick black clouds, the new vents emit a pale, hot fluid rich in methane and hydrogen and devoid of metal particles.

Also, instead of precipitating sulfide metals like black smokers do, the VDVF vents' fluids deposit talc as they cool. "We were really surprised that the vents were made from talc rather than any other minerals that we normally see," said Rachel Mills, professor of ocean and Earth science at the National Oceanography Centre of the University of Southampton in the United Kingdom. "The majority of the mineral phase making up the venting structure is the mineral talc with a bit of amorphous silica. We've just never seen this before."

Fresh Takes on Old Processes

A research team led by Bramley Murton from the National Oceanography Centre in Southhampton discovered the vents in 2010 using deep-sea video. However, the composition of the vents' fluids and deposits remained unknown until another team (with some of the same members) returned in 2013 to sample fluids, rocks, and fauna with a remotely operated vehicle. Mills said it took so long for anyone to discover the new type of vents because in addition to being far from the axis, they don't produce the particles that traditional sensors detect.

These hot vents far from the oceanic ridge may yield valuable insights into how the oceanic crust cools, members of the research team said. Scientists had suspected that the crust continues cooling farther from the ridge, but no one had ever found off-axis sources of extreme heat entering the ocean. The new vents also mark a previously unknown source of calcium, magnesium, and carbon dioxide, which could alter models of how the ocean's chemical composition fluctuates over geologic time scales.

"If we're right and this type of vent is important on slow and ultra-slow spreading ridges, then it will change our understanding of how heat gets out of the crust into the ocean and how the balance of elements and heat are maintained on the planet," said Mills.

Searching for More

The team plans to continue searching for hydrothermal vents away from the ridge to determine if they are as common as Mills suspects and to unearth their impact on ocean processes. Most of the approximately 300 known vent systems lie on the axis and are "very, very similar to each other," she said. "Now we're starting to fill in the jigsaw by finding these more esoteric, more difficult to find, more extreme type of vent systems."

By **Shannon Kelleher,** Writer Intern

Giant Balls of Bacteria Pile Up on Arctic Lake Beds, Ooze Toxin

Jessica Trout-Haney

Ball-shaped cyanobacteria colonies, nicknamed "sea tomatoes," litter the bed of a shallow Arctic lake near the shore where sunlight readily penetrates to the bottom.

Arctic lakes are stark environments full of extremes. The creatures that live in them must endure blasting ultraviolet radiation for 24 hours a day in the summer, months of icy darkness in the winter, and low levels of life-sustaining nutrients. Still, some manage to survive and even flourish under those severe conditions: Take, for example, the sea tomato.

Sea tomatoes are round, plump colonies of toxin-producing cyanobacteria. Scientists recently reported that they have observed sea tomatoes stacking up on some Greenland lake bottoms like fruit piled haphazardly on a grocery display.

The colonies start as single cells, then grow into gelatinous globules that can be as big as softballs, said Jessica Trout-Haney, a biology graduate student at Dartmouth College in Hanover, N.H. When Trout-Haney and her colleagues went to southwest Greenland to investigate naturally occurring toxins in Arctic lakes, they were surprised by what they saw.

"The bottoms of the lakes were covered in these balls," Trout-Haney said.

Although biologists have run across sea tomatoes before, the colonies in some polar lakes stand out for their "sheer size and abundance," Trout-Haney said. The largest colonies may be 25 years old, she noted.

> "The bottoms of the lakes were covered in these balls."

Examining the Arctic

Studies on toxic cyanobacteria have typically focused on bloom-forming species in temperate or tropical locations, Trout-Haney said, because researchers thought the colder lakes of the polar regions wouldn't harbor enough cyanobacteria to produce much toxin.

To test that assumption, the researchers sampled water from lakes in an ice-free area of tundra near Kangerlussuaq, Greenland. The team detected microcystin, the most widespread toxin produced by cyanobacteria, in all 19 lakes they tested (see http://bit.ly/microcystin), they reported on 18 December 2015 at the AGU Fall Meeting in San Francisco, Calif.

Microcystin causes liver damage when humans or animals consume it, Trout-Haney said. The levels the scientists found were low enough that they wouldn't cause acute sickness. Still, "low level ingestion over time is also bad—it wears down your system," Trout-Haney said.

Although sea tomatoes release microcystin into the water where they live, they aren't the only source of the toxin, Trout-Haney said. Even water from lakes where they're absent tested positive for microcystin, suggesting that other organisms also produce it.

Phytoplankton—tiny photosynthesizing creatures that live underwater—may be the source, Trout-Haney said. Turbulent waves sometimes launch the minute organisms into the air, which may provide a pathway for toxins to spread to land, Trout-Haney said—a possibility the team intends to investigate in the future.

Don't Drink the Water

"I was really surprised at how high the microcystin levels were," said Hilary Dugan, a limnologist at the University of Wisconsin–Madison, who was not involved in the study. Scientists generally think of polar lakes as pristine environments that couldn't support sea tomatoes because of scarce nutrients. This research highlights the importance of testing assumptions like that, Dugan said.

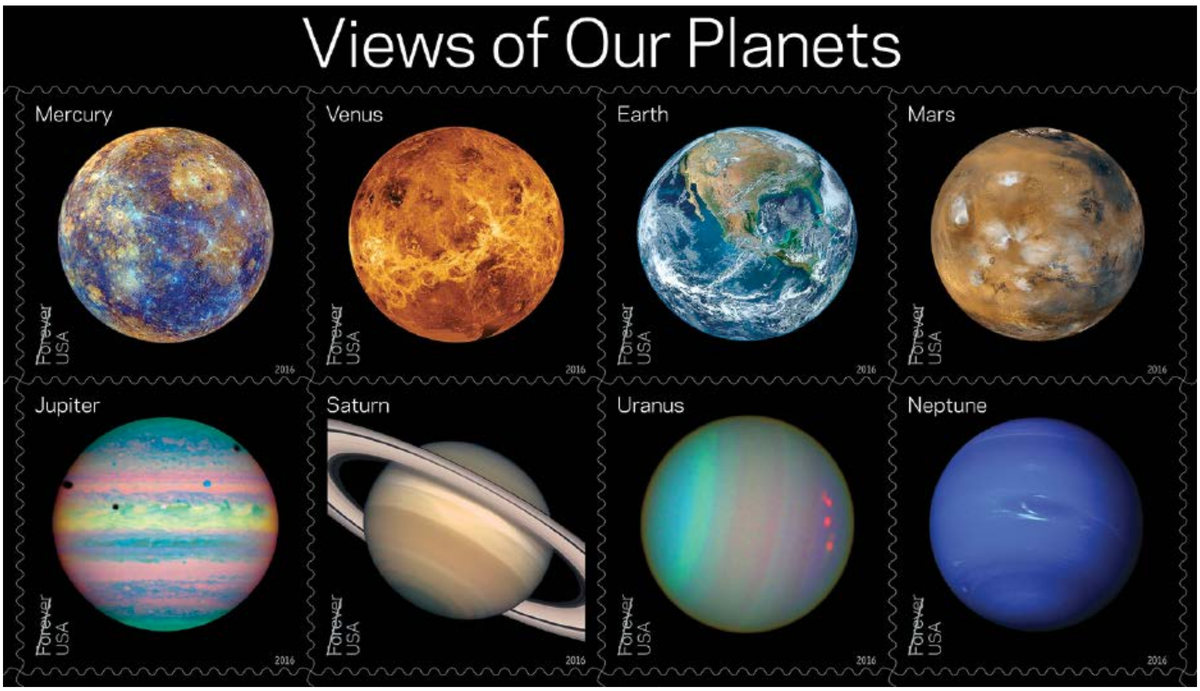
When you're out in the field "working in these environments, you just drink the lake water," Dugan added, a practice she might reconsider in the future.

By **Emily Benson,** Science Communication Program Graduate Student, University of California, Santa Cruz; email: erbenson@ucsc.edu; Twitter: @erbenson1

Jessica Trout-Haney

Sea tomatoes thrive in the harsh environment of Arctic lakes and can even weather multiple winters. Bigger sea tomatoes may be 25 years old, according to researchers.

Special Delivery: Post Office to Issue Space-Themed Stamps



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The "Views of Our Planets" sheet of 16 Forever stamps (upper half shown here) depicts full-disk images of our solar system's eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

This year's new batch of U.S. postage stamps is celebrating more than flowers, fruits, and famous Americans. The U.S. Postal Service will also issue stamps in 2016 about space exploration—both real and imagined—the agency announced shortly before this year began (see http://bit.ly/new-2016-stamps).

A 16-stamp sheet entitled "Views of Our Planets" will showcase images of our solar system's planets. Another four-stamp sheet labeled "Pluto—Explored!" will commemorate the historic first flyby of Pluto that took place last July. Other stamps will display vivid pictures of the full Moon and illustrations celebrating the 50th anniversary of the television premiere of *Star Trek.*

Celebrating Planetary Science and Space Exploration

These stamps could help spur public interest in science and engineering, said Richard Fienberg, director of communications for the American Astronomical Society. The "Views of Our Planets" stamp collection "is really quite profound," he told *Eos,* noting that each planet is not just a celestial object but a real and unique world. "Even the phrase 'Our Planets' is profound, as it reflects the recent discovery that our planetary system is one of billions of such systems throughout the galaxy."

"Photos like the ones on the stamps, and discoveries like the prevalence of planets around other stars, inspire students to become scientists and engineers, guaranteeing that the process of discovery will continue," he added.

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Celebrating the 50th anniversary of the television premiere of Star Trek, *the new* Star Trek *Forever stamps showcase four digital illustrations inspired by classic elements of the television program. Two of those illustrations are shown here.*

In 1991, the United States issued a Pluto stamp that stated "Pluto: Not Yet Explored." One of those stamps flew aboard the New Horizons spacecraft that last year visited the dwarf planet. The 2016 Pluto stamp sheet emphasizes "Pluto—Explored!"

The old stamp "served as a rallying cry for many who wanted to mount this historic mission of space exploration," said Alan Stern, New Horizons principal investigator from the Southwest Research Institute in Boulder, Colo. "Now that NASA's New Horizons has accomplished that goal, it's a wonderful feeling to see these new stamps join others commemorating first explorations of the planets."

Commemorating solar system exploration is not enough for some people. "Pluto isn't the end of the solar system; it's the beginning of the rest of the solar system, and there's much more left to explore," said Emily Lakdawalla, senior editor and planetary evangelist for the Planetary Society. "I'd like to see a new challenge from the postal service, to explore unexplored distant worlds, like Haumea, Eris, or Sedna—or even some of the worlds in other solar systems, none of which had even been discovered when the Postal Service issued its 'Pluto: Not Yet Explored' stamp in 1991." Nonetheless, she told *Eos,* she will be "thrilled" to use the new stamps on her correspondence.

By **Randy Showstack,** Staff Writer

Team Gets Firsthand Look at the New Holuhraun Eruption Site

Iceland 2015: Field Workshop on Active Lava–Water Interactions
Holuhraun, Iceland, 20–28 August 2015

Christopher Hamilton

The view south over the new lava flow at Holuhraun as it entered the Jökulsá á Fjöllum River on 18 November 2014. Interactions between the lava flow and near-surface water created the hot springs and fumaroles in the foreground. In the background a gaseous plume can be seen emerging from the main vent.

The 2014–2015 volcanic eruption at Holuhraun—the largest eruption in Iceland in 230 years—provides an exceptional opportunity to study processes important to Earth and planetary science. Lasting from 31 August 2014 to 27 February 2015, the eruption generated 1.5–2.0 cubic kilometers of lava. The flow inundated a segment of the Jökulsá á Fjöllum—Iceland's highest discharge river—resulting in unusual hydrothermal activity. The lava diverted part of the river, but a substantial flux of water continues to pass under and through the lava, emerging as steam plumes and hot springs near the flow front. The lava itself is morphologically similar to many lava flows observed on the surface of Mars, particularly in the Tharsis region.

A field workshop was organized to bring together a community of Earth and planetary scientists with diverse perspectives to examine the eruption site. On 20 August 2015, a team of 17 researchers from the United States and Canada, working in collaboration with the University of Iceland, deployed to the Holuhraun region. Over the following 8 days the researchers collected terrestrial laser scanner data, unmanned aerial vehicle images, kite aerial photography, differential global positioning system transects and profiles, streamflow data, stream temperature data, and morphological observations.

> The lava itself is morphologically similar to many lava flows observed on the surface of Mars.

The team focused on the structure and flow features within the vent cones and proximal channel, flow margin characteristics and the relationship to substrate types, the measurement of heat transported by water flowing underneath and through the lava, and detailed morphological and centimeter-scale roughness measurements of rubbly and spiny pāhoehoe. The data will provide a baseline for future studies on the modification and evolution of the lava flow and river, as well as for assessing potential geological hazards.

The researchers also documented a number of observations:

- significant variation in the heights of lava highstands within the vent cones and lava channel, with evidence of superelevation of lava flow through channel bends
- rapid formation of a lava-dammed lake due to large variations in the flux of river water reaching the lava relative to small variations in spring outflow from the flow front
- around 10^8 watts of heat transported by the water discharged through the hot springs and relationships between steam plume heights and water levels
- rubbly and spiny pāhoehoe lava textures and structures, including inflation features (e.g., tumuli) and ponds with compressional ridges and extensional rifts
- similarities and differences between the rubbly pāhoehoe breccia and surface features in this lava relative to other lava flows
- rapid redistribution of aeolian sediment along the lava flow margin (~2 centimeters/day), evidenced by the burial of a recent avian carcass

The workshop produced a new international network of collaborations that will lead to a variety of publications, proposals, and discoveries. In particular, the lava itself is morphologically similar to lava flows observed on the surface of Mars, particularly in the Tharsis region. Because of this, the Holuhraun eruption offers valuable research insight into processes on Earth and throughout our solar system. More information can be found at http://bit.ly/Arizona_workshop.

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Call Scientists Before Disaster Strikes

Picture this hypothetical scenario: Late on an October evening, the Coast Guard receives a call that a large oil spill has occurred off the north coast of Alaska. More than 200 million gallons of crude oil is gushing into frigid waters teeming with life.

In our scenario, academic scientists are uniquely positioned to minimize the impact of this crisis, and they could provide advice to avert future crises. They have studied the ecosystem for years and have worked closely with the affected communities. They are eager to contribute their expertise. If officials give them access to the spill site, they can gather data and provide input.

But those with the responsibility to contain the disaster view offers for assistance from academics as adding yet another risk and management headache to an already dangerous situation. Responders feel they have little control over the researchers, and they are unsure about the value and timeliness of the scientific contributions, given the urgency of the response. With frustration on both sides, harried agency responders proceed with their cleanup mandates, frustrated academics watch from the sidelines, and the value of collaboration goes unrealized.

> Weak links between academic expertise and governmental responders have plagued responses to large-scale environmental disasters.

Strengthening Weak Links

Unfortunately, this is the status quo for oil spill response: Qualified academic scientists have limited ability to inform disaster preparedness and response. The BP Deepwater Horizon oil disaster in the Gulf of Mexico exposed critical weaknesses in how governmental entities avail themselves of academic scientists during crises. Although some academics were involved in the Deepwater Horizon response, thanks in large part to preexisting relationships, many more could have contributed but did not have the opportunity or the ability. Five years later, many of these weaknesses remain unaddressed.

Weak links between academic expertise and governmental responders have also plagued responses to many other large-scale environmental disasters, including Hurricane Sandy and the nuclear disaster in Fukushima. Bolstering communication pathways among government, industry, and academia will help us to more effectively mitigate the consequences of disasters in any form—whether they are hurricanes, floods, or oil spills.

In the face of unpredictable yet inevitable disasters, we need a 9-1-1 emergency contact protocol to leverage the country's scientific brainpower and enable scientists to spring into action. Time is of the essence. Another disaster is always right around the corner.

Over the past year, we have coordinated the Science Partnerships Enabling Rapid Response project (see http://bit.ly/Eos_SPERR) through the Center for Ocean Solutions and Change-Labs at Stanford University. We have worked in partnership with government agencies, academic institutions, and industries to understand the cultural gaps and tensions between academia and government.

In more than 100 interviews with stakeholders involved in Deepwater Horizon and subsequent crises, we uncovered key differences in the motivations, perceptions, and values of academic scientists, government decision makers, and industry representatives that impede scientific collaboration for effective crisis response.

Distrust Impedes Collaboration

The essence of the cultural divide between academics and government decision makers lies in their differing systems of reward, time scales, and flows of information. The currency of academia is publications, whereas those who respond when disaster strikes value years of field experience. Scientists can spend several years conducting one study and getting it peer reviewed, whereas responders must make decisions, sometimes within the hour. Researchers are motivated by a spirit of scientific inquiry, whereas responders emphasize rapid and efficient decision making.

These two groups also hold different cultural norms around sharing information and transparency. Government responders often have their hands tied by legalities and potential financial liabilities, especially if a court case is likely. Academics are usually prohibited from sharing data before they are peer reviewed. Hence, the default for both groups is to hoard information but for very different reasons.

However, during the Deepwater Horizon disaster, both of these impediments were temporarily relaxed, in part, demonstrating an interest in working together. Scientists within agencies worked with their colleagues to share data publicly and reached out to editors of mainstream journals to relax publication criteria. Despite these exceptions, tensions continue, and a lack of common understanding about the objectives and priorities of both communities contributes to an underlying distrust that thwarts collaboration.

Bridging the cultural divide between agency decision makers and nongovernmental scientists can provide multiple additional benefits. When academics are exposed to disasters, they may see new opportunities to conduct research relevant to future disasters. Even more, research relevant to one type of disaster may translate to other types of disasters.

During our interviews, agency responders articulated entrenched narratives about the role academics play in crisis situations. "Academics are mostly just talking heads during a spill; they are clueless when it comes to informing a response in an on-the-ground situation," noted one of our interviewees. Similarly, academics are frustrated with the cultural silos within government. One said, "It's amazing to me that government responders came out of academia, but had no idea how to bring the knowledge we produce to bear during a crisis." An "us versus them" narrative was consistently used to reinforce stereotypes and factions.

Nonetheless, we heard a sincere desire from all interviewees to find ways to nurture collaboration and achieve the common goal of making expedient and science-informed disaster decisions.

Building Relationships Before Disasters Strike

Incorporating scientific research and methods into decision making can improve government and industry decisions before and during a crisis of any type. But to accomplish this, we need to bridge the academic-government-industry cultural divides by forging relevant partnerships before incidents occur. We propose doing so through a cross-hazards, multi-

Patrick Kelley, U.S. Coast Guard/Marine Photobank

A contract worker from Health, Safety, and the Environment (HSE) loads oily waste onto a trailer on Elmer's Island, just west of Grand Isle, La., 21 May 2010 during the BP Deepwater Horizon oil spill.

disciplinary network of scientific experts across the country linked to disaster preparedness and response decision makers.

Such a network—a "community of practice"—will create personal relationships, enhance colearning, foster norms, bolster communication, and provide the resources that are vital for active and sustained collaboration before and during disaster response. The network would build trust that effective teams need during crises, when time is short and action is demanded. Critically, this network would catalyze cross-hazard scientific learning and forge channels for scientific knowledge to flow between the academic community and disaster preparedness and response decision makers. Our proposed network—the Science Action Network (hereafter "the network")—would promote these outcomes.

First, in disaster preparedness and response, there will always be scientific questions that are unique to that event's time and place, as well as its social, ecological, and technical context. However, there are also scientific questions and methods that transcend specific disasters, such as which communities are affected and how we engage them effectively. The network would serve as a clearinghouse for general and specific crisis response research evidence.

Second, the network would facilitate the *process* of scientific exchange between academics and government decision makers to help them prepare for and respond to all types of disasters. For example, there are opportunities to streamline protocols or techniques for effectively communicating scientific issues to the press and public, systems of rapid peer review, trusted platforms for data sharing or disaster site access, and agreements around intellectual property rights and confidentiality of crisis data.

Bridging the Divide

The network would be composed of academic and professional scientists who would work with regional governmental planning and response bodies. Regional academic liaisons in each of 10 existing governmental response regions in the United States would forge new ties between university researchers and governmental agencies such as the National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the U.S. Coast Guard, and the Federal Emergency Management Agency. These new connections would ensure that those agencies have streamlined and formalized access to relevant science before and during disasters.

On a national level, the network would help government agencies learn from various disasters by cross-pollinating relevant scientific discoveries and data and integrating science into decision making. Scientists in the network would benefit from new research collaborations, streamlined access to funding, and the opportunity to contribute meaningfully to communities.

In the case of the hypothetical oil spill off the coast of northern Alaska, the network would have already solidified relationships between responders and the local academic scientists with relevant expertise before the spill, building the trust to enable resource sharing and more effective collaboration and less confusing public communications during the crisis. As Admiral Thad Allen, the national incident commander for the Deepwater Horizon response, remarked, "A crisis is not the time to begin exchanging business cards."

Deepwater Horizon catalyzed new relationships across regions, institutions, and disciplines. It generated and inspired excellent science and opened new channels for integrating scientific expertise and information into crisis response. The response also illuminated persistent fault lines between scientific communities and decision makers. As humans continue to increase the variability of weather and climate and society grows increasingly complex, we cannot afford to ignore these fault lines, especially where bridging them is quite feasible.

The Science Action Network would build the pathways we need to promote scientific collaboration before and during crises, increasing the effectiveness of disaster management in the face of complex unknowns that threaten our human communities and the resources on which we depend. We can no longer afford to isolate knowledge from action. Fortunately, those equipped with relevant scientific knowledge and those with the knowledge and authority to prepare and respond have the same goal: to make the right science-informed decisions.

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Taking the Pulse of the Earth's Surface Systems

Elizabeth Hajek

The proposed Earth Surface Observatory initiative would make a detailed assessment of the past and present state of the critical zone, the surface and near-surface region of Earth where life persists. Shown here is a cross section of the critical zone in the Piceance Basin of western Colorado.

Are we approaching tipping points with regard to the interwoven physical, biological, geochemical, and human dynamics of Earth's skin? What is the state of Earth's critical zone, the surface and near-surface region of Earth where life persists? How can observed changes in Earth's climate and biota help us make better decisions in the Anthropocene—the age of humans?

Human activities are rapidly changing Earth's surface [*Hooke*, 2000; *Wilkinson*, 2005] and its ecological and biogeochemical systems. These anthropogenic effects have consequences that will persist or deepen with time. For example, carbon dioxide levels in the atmosphere have recently surpassed 400 parts per million, the highest in several million years, and these elevated levels and their consequences will persist for many millennia to come.

Effects of this rise include diminished glaciers, thawed permafrost, higher sea levels, drowned coastal land, and acidified oceans. Population growth and changing land use are stressing freshwater resources [*Ferguson* and *Gleeson*, 2012]. In much of the world, agriculture and development have markedly changed the flow of sediment and nutrients, polluting rivers, lakes, and coastal ecosystems with fertilizers [*Syvitski et al.*, 2005; *Tilman et al.*, 2001].

These various stressors interact in complex ways [*Thornton et al.*, 2007]. However, attempts to quantify a baseline or monitor effects of these ongoing changes have been limited in geographic extent and the range of variables and processes that they consider. Recently, the National Science Foundation (NSF) tasked a subset of the Earth surface process community to brainstorm how a targeted investment of research and infrastructure might address this challenge.

Since September 2014, the group has been developing an initiative to capture the past, present, and future status of Earth's surface systems—the pulse of the planet. Here we describe that vision and seek broad community input.

The Earth Surface Observatory

To predict how Earth's surface and climate will change—and to improve decision making—it's pivotal to map the critical zone across entire continents and reconstruct Earth's paleoclimates during times of major change in geologic history. With planning and vision, we can achieve this goal within several decades.

As a first step, we propose a 10-year Earth Surface Observatory initiative, consisting of three complementary components. First, a Paleoenvironmental Reconstruction Program would help us understand how Earth's surface responded to past perturbations. Second, an Earth Rover campaign would characterize the present state of the critical zone. Third, a Distributed Analytical and Experimental Laboratory Network would provide scientists open access to existing and future cutting-edge analytical and experimental facilities.

Together, these three components represent a holistic approach to capturing the past, present, and future pulse of Earth's surface systems. This infrastructure would better equip the community to address the research priorities that the National Academy of Sciences has laid out in several reports and white papers (available from the National Academies Press):

- *Landscapes on the Edge* (2010)
- *Understanding Earth's Deep Past: Lessons for our Climate Future* (2011)
- *New Research Opportunities in the Earth Sciences* (2012)
- *Challenges and Opportunities in the Hydrologic Sciences* (2012)

The Earth Surface Observatory Initiative builds upon and leverages existing NSF-funded projects yet goes beyond those efforts in its goals of understanding deep time processes and achieving continental-scale data products to open vast new realms of inductive inquiry.

Tapping the Earth's Archives

The Earth has now entered the Anthropocene, the geologic epoch in which humans are altering the Earth's ecosystems to an unprecedented extent. This plunge into uncharted territory highlights the need to tap Earth's archive of natural experiments—the stratigraphic and paleontologic record, which documents how different Earth systems have responded to past climate change.

One of the best ways to assess risk and predict changes to Earth's surface and climate systems is by knowing what contributed to resilience and sensitivity of landscapes, environments, and ecosystems in the past. To accomplish this, we need a concerted effort to reconstruct Earth's environments at key windows in geologic history—the Paleoenvironmental Reconstruction Program component of this effort.

We propose a coordinated program, based primarily on continental drilling, to investigate rock records, targeting periods when

Earth's surface systems underwent dynamic change. These episodes of environmental upheaval can serve as "distant mirrors" [*Tuchman*, 1987] for our own times. These drill cores, along with other geological data collected on site, would allow us to reconstruct a detailed picture of how Earth's biological, geochemical, and geophysical systems responded to significant historical climate changes.

The goal is to organize diverse, interdisciplinary efforts around common themes and time intervals. This initiative would also address the urgent need for infrastructure by providing access to drilling rigs, designating a centralized location to curate recovered cores, and expanding access to state-of-the-art analytical facilities for core analysis.

Exploring Planet Earth

Quantifying environment parameters such as the movement of water, sediment, and solutes is key to understanding Earth dynamics [*Anderson et al.*, 2004]. But to understand how they change at a continental level, we first need a common set of baseline measurements across a wide range of climates and geology. These would calibrate remote sensing products for the continental mapping initiative and also serve as inputs for predictive Earth systems models.

Our proposed Earth Rover campaign spans all 25 phystographic provinces in the United States, with urban, rural, and agricultural sites (about 75 sites total). This campaign would yield information about the relevant geologic, geophysical, geochemical, hydrologic, and biotic properties and the deep history of the critical zone. Within each physiographic province, we would choose sites on the basis of geology and vegetation, leveraging efforts at existing long-term observatories.

Field data collection efforts would feature "Earth rover" vehicles with cutting-edge instrumentation that perform a common set of measurements at each site. These rovers would move from site to site, collecting data using methods that are too expensive or labor intensive to be practical for long-term monitoring at fixed instrumentation sites.

We would monitor each site for 10 years in an approach with four phases. During phase 1 (years 1–3), airborne sensors would map the area using lidar, hyperspectral, thermal, reflectance, gravity, magnetics, time domain electromagnetic, and geochemical data. The resulting data would then serve as inputs to site-based models of Earth surface processes in phase 2.

The first two phases would inform experimental design for subsequent intensive data collection over several weeks at each site using a dedicated mobile Earth rover unit (phase 3; years 2–6). The rovers would measure biotic and abiotic properties and track the movement of moisture and nutrients through the atmosphere, surface, and underground.

These data would be used as a baseline to calibrate remote sensing algorithms and develop relationships among remote sensing products (e.g., thermal and reflectance-based imagery) and other critical zone properties (e.g., soil moisture). In phase 4, beginning in year 5, another rover would return to a subset of sites to characterize time-sensitive responses to infrequent events (e.g., fire, storms, land use changes) or seasonal changes.

An Accessible Network of Laboratories

In addition to the wealth of new data that the rovers would collect, we also propose a complementary investment in laboratories and facilities—the Distributed Analytical and Experimental Laboratory Network component. Experiments and high-precision analyses of Earth materials are important tools for understanding Earth surface processes, biogeochemical systems, and the critical zone. This initiative would broadly integrate and expand access to manipulative experiments and high-cost analytical work that are fundamental to synthesizing field and theoretical efforts to understand Earth surface processes.

Building on the success of existing laboratory networks such as the National Nanotechnology Coordinated Infrastructure program, we envision a concerted effort to link and improve existing facilities, as well as a distributed network of six new "full-spectrum" laboratories, each with a scope reaching from the benchtop to the field and from the nanoscale to the landscape scale. Facilities would work with the Earth Rover field campaign and the Paleoenvironmental Reconstruction Program and link researchers across Earth surface subfields, including microbiology, geochemistry, sedimentology, geomorphology, ecology, and hydrology.

Reaching Out for Feedback

This three-pronged infrastructure investment is necessary to comprehensively assess the sensitivity of Earth's surface to future climate and land use changes and to manage risks to our critical zone habitat. These three components would also provide an abundance of opportunities for training, outreach, and research coordination, including distributing inexpensive sensors to citizen-scientists, schoolyard partnerships with the Earth Rover campaign and Paleoenvironmental Reconstruction Program, and teacher-training programs run by funded staff members.

We invite the community to leave comments on this article online (see http://bit.ly/Eos_Larsen_opn). Specifically, we seek suggestions for how this initiative might be best integrated into existing centers and programs for data collection and dissemination such as the NSF Critical Zone Observatories and EarthCube.

Acknowledgments

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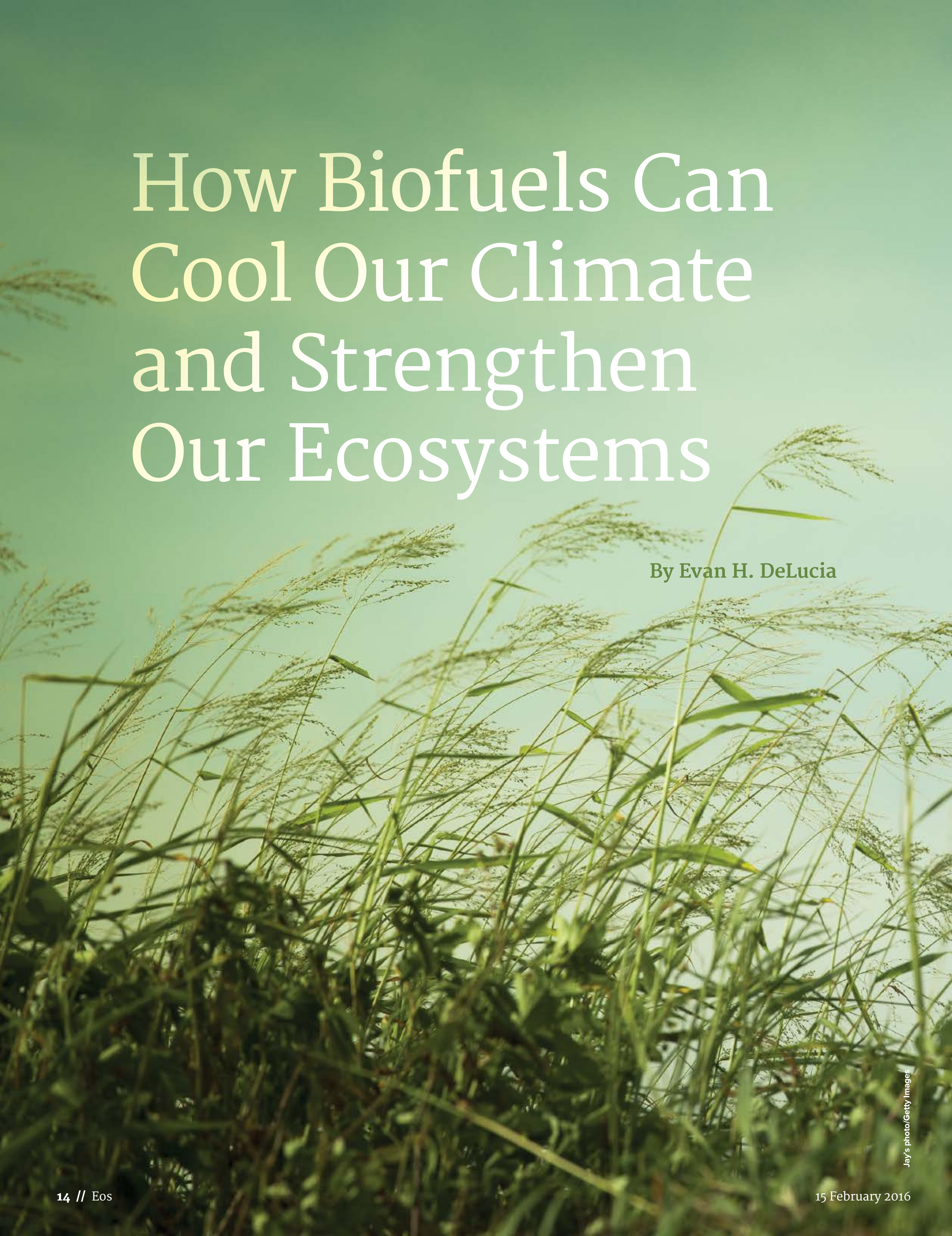
How Biofuels Can Cool Our Climate and Strengthen Our Ecosystems

By Evan H. DeLucia



Jay's photo/Getty Images

Critics of biofuels like ethanol argue that they are an unsustainable use of land. But with careful management, next-generation grass-based biofuels can net climate savings and improve their ecosystems.

Miscanthus grass, a source for second-generation biofuels, can be grown on land that is not suitable for raising food crops.

As the world seeks strategies to reduce emissions of carbon dioxide (CO_2) into the atmosphere, bioenergy is one promising substitute for fossil fuels [*Somerville et al.*, 2010]. Currently, the United States uses the starch component from roughly 40% of its corn harvest to produce ethanol for the transportation sector (see http://www.nass.usda.gov/).

Cornstarch production is technologically simple—a so-called first-generation bioenergy technology. However, growing corn requires a lot of fertilizer and field preparation that ultimately depend on fossil fuels, tempering the net carbon savings.

Currently, the United States uses the starch component from roughly 40% of its corn harvest to produce ethanol for the transportation sector.

Because of this, researchers have focused on developing fuel production using more advanced methods and second-generation bioenergy crops. These methods make liquid fuel, primarily ethanol, from lignocellulose, which composes the structural elements of plants, leaves, stalks, and stems. Because many of these crops are perennials (they grow back year after year), they often require less fertilizer and tillage, avoiding many of the negatives associated with corn and other annual crops that need intensive management.

A challenge with second-generation energy crops, however, is that they yield much less energy—lignocellulose produces less than one third of the energy per unit mass compared to fossil fuels. Because of this low energy density, the United States would need to invest a considerable amount of land to meet a significant part of national demand, a land area almost the size of Wisconsin to meet the mandate for 32 billion gallons of biofuel set forth by the U.S. Environmental Protection Agency's Renewable Fuel Standards program [*Hudiburg et al.*, 2015].

The conversion of current land uses and management practices to the cultivation of bioenergy crops directly affects the climate system and is a fundamental process underlying the ecological sustainability of bioenergy production, as well as the ability of bioenergy crops to mitigate climate change. Where conversion of native prairie to corn negatively affects climate by releasing CO_2 and other greenhouse gases to the atmosphere, planting second-generation grass-based biofuel crops on marginal or degraded land can reduce our carbon footprint and provide other beneficial ecosystem services.

Changing the Landscape Changes Our Climate

Public discussion of climate change often focuses on the atmosphere. As greenhouse gases (GHGs) like carbon dioxide, nitrous oxide, and methane accumulate in the atmosphere, they warm the planet by absorbing infrared radiation. But that's not the whole picture: Those greenhouse gases are also constantly cycling between the atmosphere and the land (Figure 1). Therefore, changes in land use, vegetation, and how we manage it affect climate by altering that exchange.

The metabolisms of plants and soil microbes help to regulate the exchange of GHGs with the atmosphere, as these molecules or their precursors are stored in biomass and soil. Clearing a native forest, for example, releases large quantities of carbon stored in biomass and soil to the atmosphere ("storage"; Figure 2). Indeed, creating and managing farmland contribute more than 14% of the world's GHG emissions (U.S. Environmental Protection Agency, global greenhouse gas emissions data, 2015; see http://bit.ly/global_greenhouse_gas).

Terrestrial ecosystems also affect climate on local scales by regulating the exchange of energy between the land and atmosphere (Figure 1) [*Davin et al.*, 2014; *Zhao and Jackson*, 2014]. Land covered with vegetation generally absorbs more sunlight than bare soil, contributing to local warming. Work-

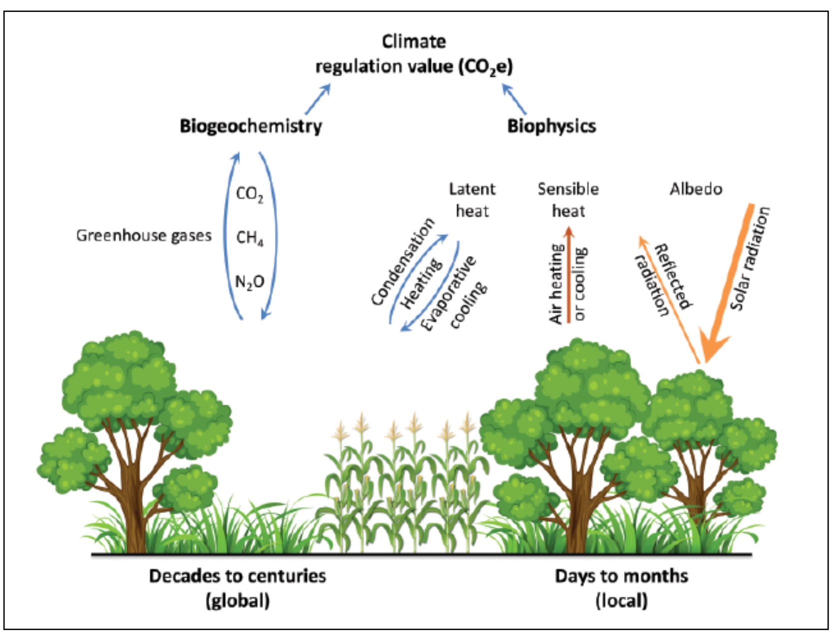


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Fig. 1. Terrestrial ecosystems affect the climate system by influencing the exchange of greenhouse gases between the land surface and the atmosphere (biogeochemical regulation) and by influencing the exchange of energy (evapotranspiration and albedo) with the atmosphere (biophysical regulation). Biogeochemical processes affect the concentration of greenhouse gases in the atmosphere, influencing global climate on decadal time scales or longer, whereas biophysical processes cause local cooling or warming over days and months.

ing against this, when water evaporates and passes into the atmosphere from soil and vegetation (known collectively as evapotranspiration), it carries heat away from the land, causing local cooling. Thus, forest clearing would reduce the cooling effect of evapotranspiration but would increase the reflectivity of the surface (or its albedo), allowing it to reflect more radiation.

However, global effects are complicated because evapotranspiration means more moisture in the atmosphere, which can increase cloud cover, affecting the global radiation balance. Also, when the moisture condenses into clouds elsewhere, it releases its latent heat, which can cancel the local cooling effect [*Pielke et al.*, 2002; *Snyder et al.*, 2004]. Unlike GHGs that have a locally weak but globally strong effect on the atmosphere, albedo and evapotranspiration affect climate locally [*Bright*, 2015].

By normalizing the warming (or cooling) potential of nitrous oxide (N_2O), methane, albedo, and evapotranspiration to the warming potential of CO_2, the contribution of different ecosystems to climate regulation can be expressed as a single metric: the climate regulating value (CRV) [*Anderson-Teixeira et al.,* 2012]; this value provides an integrated index of the direct effects of land clearing on the surface energy budget, where the greater the CRV is, the greater the cooling effect is (Figure 2).

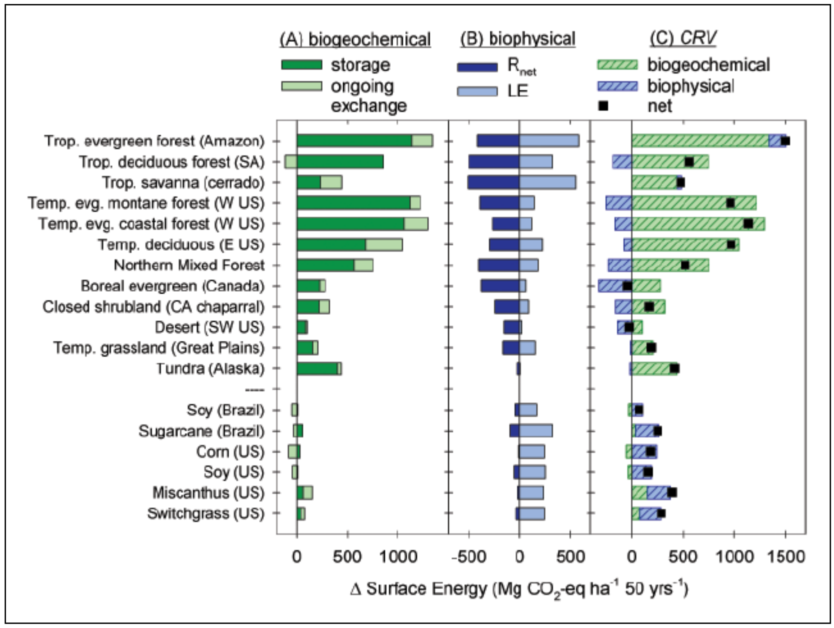

Fig. 2. (a) Biogeochemical climate services reflect the greenhouse gases that would be released from land clearing and the change in ongoing exchange with the atmosphere. (b) Similarly, land clearing affects biophysical climate services, albedo, related to net radiation (R_{net}), and latent heat flux from evaporation (LE), related to changes in evapotranspiration. Positive values represent a net cooling effect on the atmosphere. (c) The sum of greenhouse gases and biophysical factors is the climate regulating value (CRV) of an ecosystem. Values are normalized to the warming potential of carbon dioxide (CO_2) and are expressed as equivalents to megagrams of CO_2 per hectare relative to bare ground over a 50-year time frame. Replacing an ecosystem with a high CRV with that having a low value would have a net warming effect on the atmosphere and vice versa. Reproduced from Anderson-Teixiera et al. *[2012].*

Long-Term Strategic Planting

In native forests and other ecosystems with large carbon stocks, biogeochemical processes—those processes that store and exchange GHGs with the atmosphere—can play a larger role in regulating the climate than biophysical processes such as changes in evapotranspiration and albedo (Figure 2). The opposite can be true for perennial grasses that don't store much biomass but have high evapotranspiration and albedo.

Therefore, displacing native forests, particularly tropical forests, with annual or perennial crops for energy production will, in most cases, have a net warming effect on the atmosphere, releasing large quantities of carbon stored in biomass and soil (Figure 2). But replacing annual crops or placing high-yield bioenergy crops on marginal land (that is, land that cannot produce high-value crops) has a very different effect.

Replacing annual crops with perennial grasses such as miscanthus and switchgrass would pull carbon out of the atmosphere and return it to the ground (Figure 2). These crops allocate a large fraction of their biomass below ground in their root systems, and they can rapidly build up carbon stores in soil, reversing losses associated with frequent tillage, particularly on degraded or heavily tilled soils [*Anderson-Teixeira et al.*, 2009; *Anderson-Teixeira et al.*,2013; *Powlson et al.*, 2011].

In terms of climate effects, this is doubly helpful. In addition to displacing fossil fuels by providing a renewable

Planting second-generation grass-based biofuel crops on marginal or degraded land can reduce our carbon footprint and provide other beneficial ecosystem services.

biofuel, replacing low-CRV annual crops with high-CRV perennial grasses would have a net cooling effect on the atmosphere because of the changes in biogeochemical and biophysical properties. In particular, the increased albedo from perennial grass and the heat carried away by evapotranspiration can amount to a considerable cooling effect compared to annual row crops [*Georgescu et al.*, 2011].

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Flowering stalks of miscanthus, a perennial grass that could be used for biofuel..

The U.S. Midwest: From Carbon Source to Sink

Approximately 40 million hectares in the United States, mostly in the Midwest, are planted with corn. Only 8% of their harvest directly feeds humans; most of the rest (73%) is for feeding livestock and producing ethanol (see http://www.nass.usda.gov/). Displacing corn currently grown for ethanol with high-yielding perennial grasses would have enormous environmental benefits, without displacing land used for food production. *Davis et al.* [2012] predict that replacing ethanol-bound corn with perennial grasses would reduce emissions of GHGs to the atmosphere while increasing soil carbon. The emissions of N_2O in particular would be reduced because perennial grasses require so much less nitrogen than corn [*Smith et al.*, 2013]. Over the entire region, this transition would convert soils in the Midwest from a net source to a net sink for GHGs while simultaneously increasing fuel production and reducing the contamination of groundwater by fertilizer-derived nitrate.

> Replacing annual crops with perennial grasses would pull carbon out of the atmosphere and return it to the ground.

Prime corn land is expensive. Restricting most bioenergy grasses to more affordable marginal land would also drive a reduction in U.S. GHG emissions, albeit a smaller one than replacing corn ethanol, and would still meet the Renewal Fuel Standard's mandate for 32 billion gallons of renewable biofuel, with negligible effects on food crop production [*Hudiburg et al.*, 2015].

The biophysical processes will also help to regulate climate. Evapotranspiration would increase slightly—less than 10% [*VanLoocke et al.*, 2010]—but combined with an increased albedo, that's enough to provide an additional local cooling effect.

The Promise and Challenges of a Bioenergy Landscape

In addition to displacing CO_2 emitted from fossil fuels, the expansion of perennial bioenergy crops in the U.S. Midwest will likely have positive effects on the climate system. This, however, is not necessarily the case elsewhere. In much of the United States west of the 100th meridian (a line that roughly bisects the Dakotas and Texas), the ability of the atmosphere to remove water (potential evapotranspiration) exceeds precipitation. There, the irrigation necessary for energy crops would pose severe environmental challenges.

In Southeast Asia, displacing native forest with palm oil plantations, in part for biodiesel, has increased the amount of atmospheric GHGs and hurt biodiversity [*Danielsen et al.*, 2009]. Furthermore, by increasing grain

prices, displacing food crops with bioenergy crops may encourage deforestation in the tropics for expanding agriculture [*Searchinger et al.*, 2008].

We must take care to avoid these unintended negative consequences of expanding lignocellulosic bioenergy production. But with appropriate financial incentives [*Dwivedi et al.*, 2015], there are many strategies to use land sustainably to contribute to the U.S. demand for transportation fuel: the use of marginal or underproductive lands [*Gelfand et al.*, 2013] or replacing intensively managed corn for ethanol with high-yielding, low-input perennials. When annual crops that require intensive management are replaced with high-yielding perennial plants, bioenergy crops can simultaneously reduce the emission of GHGs to the atmosphere and improve the health of agricultural landscapes [*Werling et al.,* 2014].

> We must take care to avoid the unintended negative consequences of expanding lignocellulosic bioenergy production.

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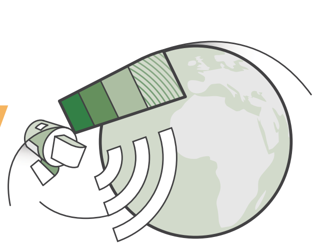

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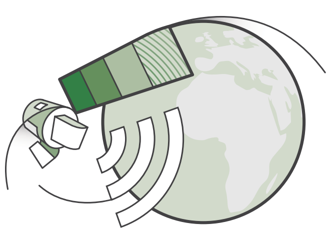

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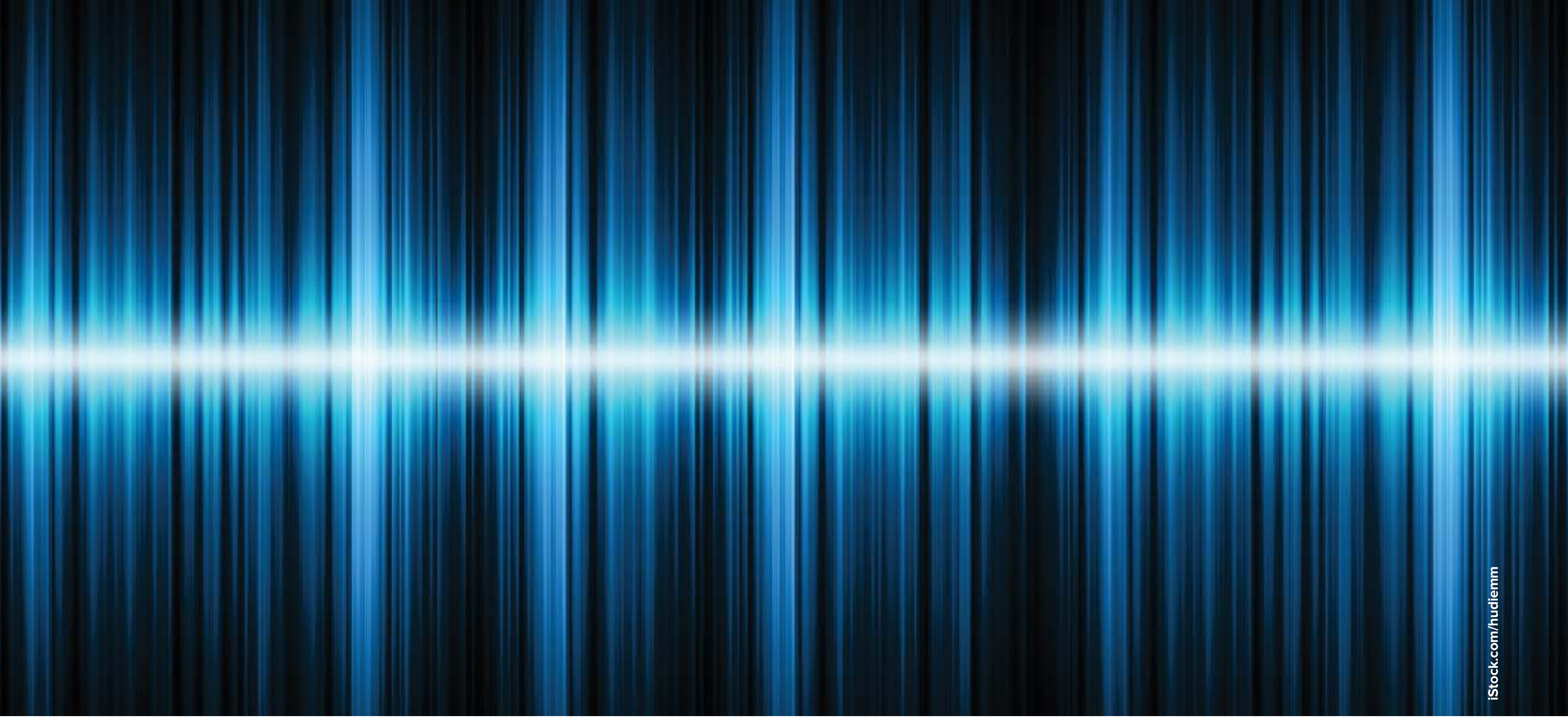


Using Sounds from the Ocean to Measure Winds in the Stratosphere

By Marie Arrowsmith, Stephen Arrowsmith, and Omar Marcillo

Stratospheric winds deflect acoustic waves from the oceans. With the right data and the math to analyze them, these waves tell us about the weather aloft.

Improving weather forecasts and climate models over both short and seasonal timescales requires a better understanding of the stratosphere [*Shaw and Shepherd,* 2008]. In this atmospheric layer (10–50 kilometers in altitude), temperature increases with altitude because of an increase in ozone, which absorbs ultraviolet light. This layer also plays a crucial role in weather generation.

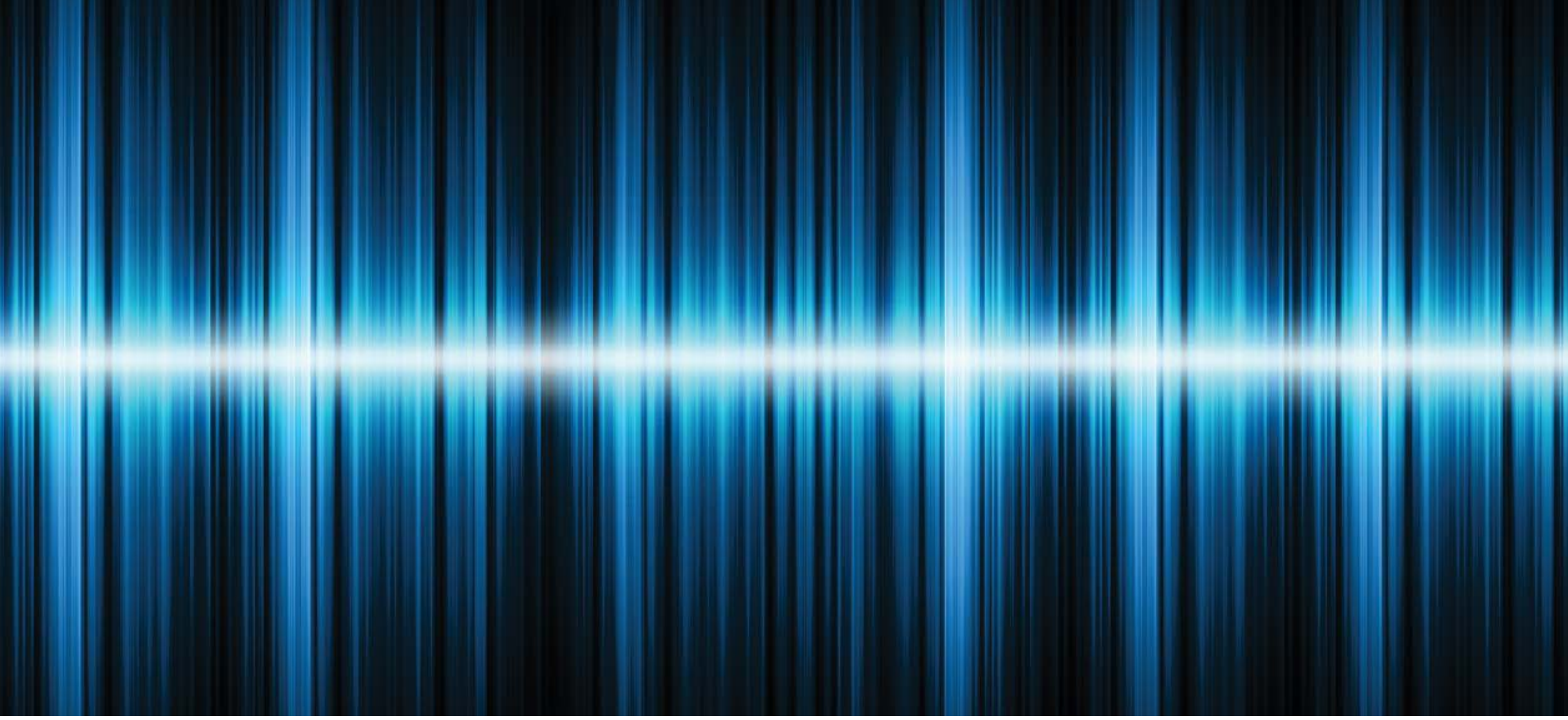
Many properties of the atmospheric state—temperature, pressure, and density—are well understood or well modeled in the stratosphere. However, a critical property, wind state, is poorly understood because it varies considerably across time and space and because of a lack of direct measurements, which are generally limited to discrete samples obtained by very specialized instruments. The need for new ways to measure stratospheric dynamics is a topic of active study, including a major scientific initiative in Europe [*World Meteorological Organization,* 2013].

Recently, lidar has been employed to provide more detailed stratospheric wind measurements [*Baumgarten,* 2010]. Because aerosol and molecular densities are lower in the stratosphere, this technology requires a complicated setup of large-aperture telescopes and powerful lasers; such facilities are expensive to build and operate, and they provide wind profiles only at their particular location.

Using Sound to Study Winds

In parallel with improving models and measurements of stratospheric properties, there has also been a renaissance of research on low-frequency acoustic propagation. The field has been revitalized by nuclear explosion monitoring efforts and the ongoing installation of the International Monitoring System (IMS) infrasound network.

Infrasound—sound below the frequency threshold of human hearing—can be detected at large distances because the atmosphere absorbs very little of it. Infrasound waves are refracted in the stratosphere because a combination of increasing heat and wind near the stratopause, the boundary between the stratosphere and mesosphere (50–100 kilometers in altitude), affects the speed



of sound in the atmosphere. Thus, the refraction of infrasound is dependent on stratospheric temperature and wind state.

A mathematical formulation known as inversion can be used to infer temperature and wind state from the observed changes in infrasound. Until recently, studying wind using inversion of infrasound data required known, short-lived events such as large chemical explosions. However, the concept of using continuous measurements to quantify stratospheric winds was proposed more than 40 years ago, when *Donn and Rind* [1972] suggested that microbaroms—ocean-generated infrasound—could be used to infer upper atmospheric conditions.

Microbaroms originate when ocean waves having similar wavelengths and traveling in approximately opposite directions interact. Several factors have limited progress in using inversion of microbarom signals for characterizing the atmospheric state:

- Microbaroms are radiated from large areas of ocean.
- Their location is variable and dependent on the ocean state.
- Microbarom signals are continuous and narrowband (they occur over a narrow range of frequencies), in contrast to the transient broadband signals used in other studies.

The first two issues increase the number of variables that must be accounted for when inverting infrasonic observations for winds, requiring many more observations to solve the governing equations. The third issue degrades our ability to measure propagation time differences between arrays using cross-correlation techniques.

In 2013, we proposed an algorithm for inverting for winds in the stratosphere using transient sources with unknown location [*Arrowsmith et al.,* 2013]. Recently, *Fricke et al.* [2014] demonstrated that microbarom correlations from waves refracted in the troposphere can be observed at distances of up to approximately 40 kilometers using single-channel stations, which addresses the narrowband observation issue.

Our work with the Norwegian Stratosphere (NORSE) experiment addresses the major unknown: whether observable waveform correlations can be related to the refraction of waves, and thus the conditions, in the stratosphere.

A Microbarom Network in Norway

Recently, a team of researchers organized a field experiment to study microbarom signals that are refracted in the stratosphere to characterize the winds using waveform correlations. This effort is led by the Laboratory Directed Research and Development program at Los Alamos National Laboratory (LANL), and team members come from LANL, the Andoya Space Center (Norway), the Leibniz-Institute of Atmospheric Physics (Germany), and the Norwegian Seismic Array (NORSAR) research foundation (Norway).

Stephen Arrowsmith

A view from one of the elements at the SKD infrasound array near Andenes, Norway, looking west at the brightest time of day during October, the last day the Sun came across the horizon in 2014.

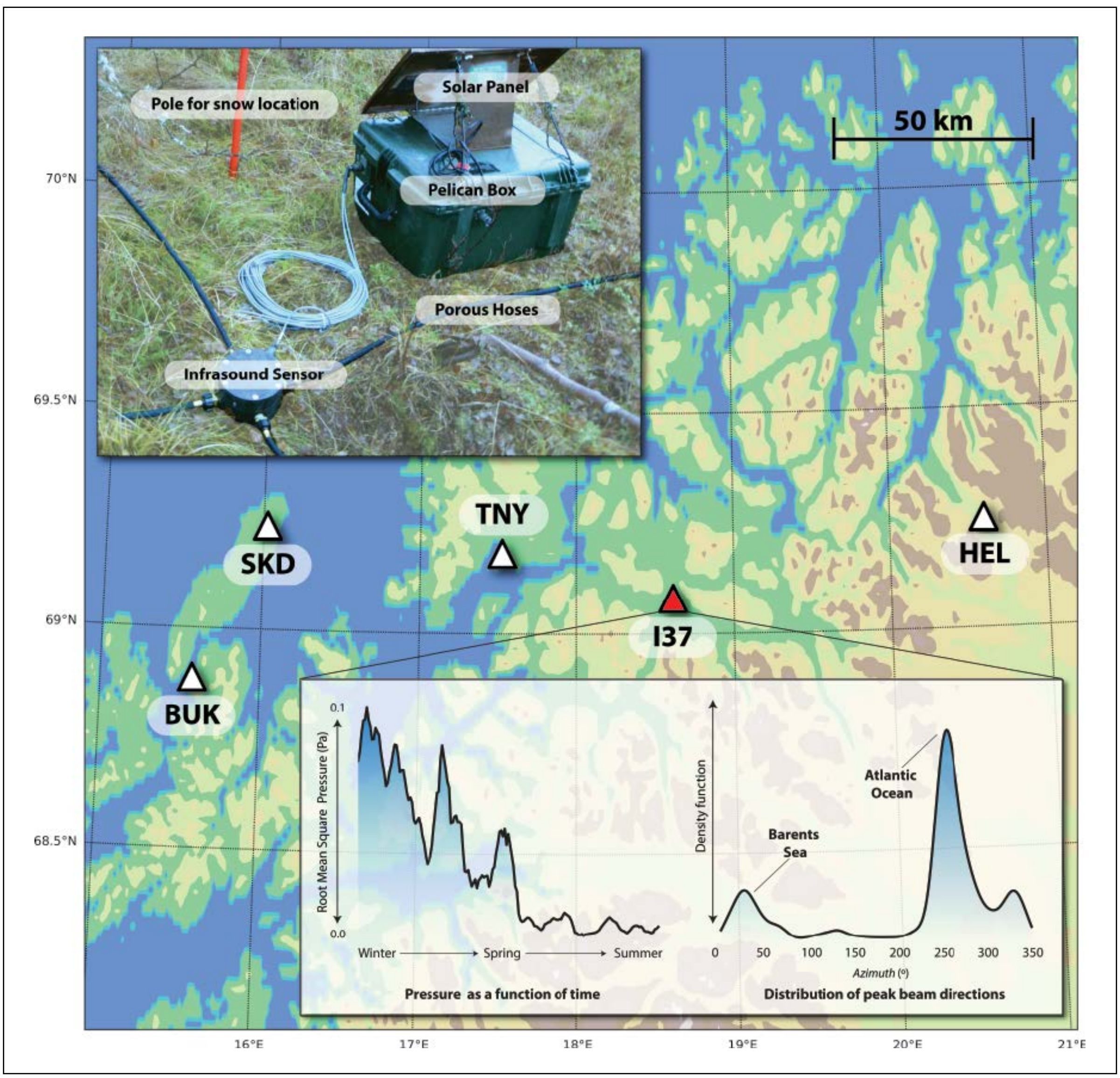
Our team selected a field area in northern Norway, located near both the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) and the IMS I37 infrasound array. ALOMAR has the capability to make direct measurements of stratospheric winds that will provide an independent validation of the infrasound-derived measurements [*Baumgarten*, 2010]. We analyzed data from the I37 array to configure the network, and we deployed it beginning in 2014. Signals are strongest in the winter months, propagating from a west-southwest direction (Figure 1). The correlation of microbarom signals is strongest along the direction of propagation. Because our proposed technique [*Arrowsmith et al.*, 2013] depends on strong correlations, we designed the network to lie along the axis of propagation at I37.

In October 2014, the NORSE team deployed two four-element infrasound arrays near ALOMAR. We used one full winter of data collected from these two arrays (SKD and BUK, Figure 1) to finalize the network design and conduct on-site tests of various noise reduction systems. In April 2015, we installed two additional four-element arrays (TNY and HEL, Figure 1), which will operate until April 2016. For optimal spatial filtering (beamforming), the distance between sensors in the array is approximately 850 meters, or half a microbarom wavelength.

Preliminary Results and Future Work

Our team analyzed data from the SKD, BUK, and I37 arrays. Strong microbaroms were present at all three arrays and exhibited similar trends in direction and pres-

Fig. 1. The Norwegian Stratosphere (NORSE) experiment involves the installation of four arrays near the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) and the International Monitoring System (IMS) I37 infrasound array in Norway. The top inset shows a typical station setup. The bottom inset shows that microbarom pressure at I37 is strongest during the winter months. Microbarom beam directions from separate sources in the North Atlantic and Barents Sea are prominent peaks in the bearings along the horizontal axis in the graph at right.



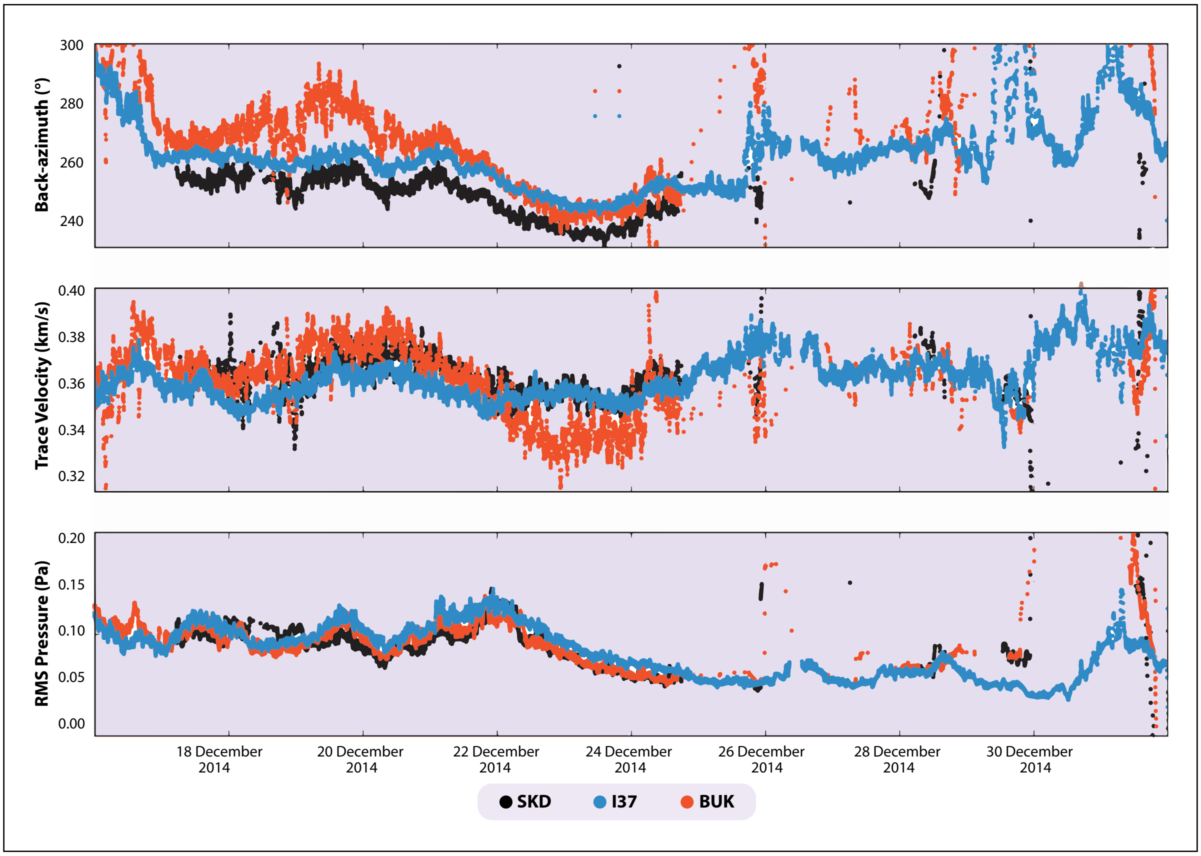


Fig. 2. An analysis of (top) the direction, (middle) trace velocity, and (bottom) power of the dominant microbarom signals observed at the SKD, I37, and BUK arrays from 16 December 2014 through 1 January 2015. RMS = root mean square.

sure as a function of time (Figure 2). This result provides clear evidence that microbarom signals at the three arrays originated from the same broad North Atlantic Ocean source, and they encountered similar atmospheric conditions from source to receiver.

These are the conditions that must be met to use microbarom observations to invert for wind in the stratosphere. If these conditions had not been met, there would have been too many variables, the inverse problem would have been unconstrained, and we would not have been able to apply the inversion method to analyze the data.

> This result provides clear evidence that microbarom signals at the three arrays originated from the same broad North Atlantic Ocean source.

The observations also show that properties of microbaroms are highly dynamic: The direction and power of the signals change over time, with acoustic noise levels at each individual array strongly affecting the estimates. For example, high noise levels from 26 December 2014 to 1 January 2015 caused gaps in the observations at SKD and BUK.

It is likely that variations in noise will degrade our ability to perform inversions at certain times; however, our preliminary data analysis suggests that the observations of this fickle oceanic source have enough consistency between arrays—and that this consistency lasts for adequate periods of time—for this data set to yield unique constraints on the dynamics of the stratosphere.

Current numerical weather and climate models are capped at about 35 kilometers in altitude and do not properly account for dynamic coupling between the troposphere and stratosphere. Although measurements using low-frequency sound may provide just one part of a broader suite of measurements needed to characterize the stratosphere at the necessary resolution, a better understanding of the dynamics of the stratosphere ultimately has strong potential to improve our ability to forecast weather and climate.

Acknowledgments

The NORSE team comprises a large number of people. Diane Baker played a critical role in organizing the entire

experiment from inception through deployment. Philip Blom performed numerical simulations that refined our network design. Sandra Blindheim, Rory Mcdougall, and Jan Arne Soreng assisted with network installation and maintenance. Young-Joon Kim and Doug Drob gave technical input on atmospheric physics. Jens Hildebrand and Gerd Baumgarten will provide validating lidar measurements. Tormod Kvaerna provided technical expertise. We thank Jose Fuentes, two anonymous reviewers, and Alexis Le Pichon for their insightful comments on an earlier draft of this article. This work was supported by the Laboratory Directed Research and Development program at LANL. LANL is operated by Los Alamos National Security, LLC, for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. Sandia National Laboratories is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

A better understanding of the dynamics of the stratosphere ultimately has strong potential to improve our ability to forecast weather and climate.

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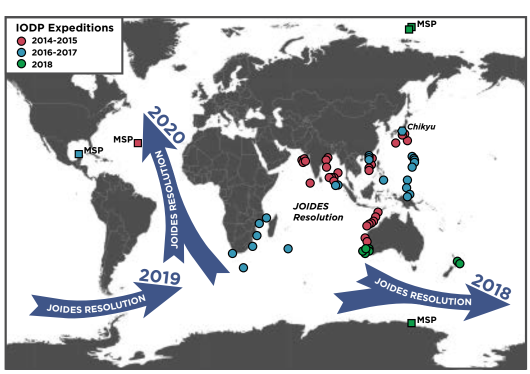
The JR is planned to operate 10 months per year in 2018 and 2019 under a long-term, global circumnavigation track based on proposal pressure. Future JR expeditions are projected to follow a path from the southwestern Pacific Ocean, through the Southern Ocean, and into the Atlantic Ocean for opportunities starting there in 2019. The JR is then expected to operate in the Atlantic, Mediterranean, Caribbean, and Gulf of Mexico starting in 2020. Although JR proposals for any region are welcomed, pre- and full proposals for these future operational areas are strongly encouraged.



MSP expeditions are planned to operate once per year on average, and proposals for any ocean are welcomed. *Chikyu* operations will be project-based, and new proposals to use *Chikyu* in riser mode must be Complementary Project Proposals (with cost-sharing).

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AGU is promoting use of new open community identifiers, such as International Geo Sample Numbers (IGSNs) for field samples like this coral. In January, AGU and about a dozen other publishers committed to including researcher identifiers called ORCIDs in all published papers this year.

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These digital identifiers hold great usefulness for securing integrity in science, providing efficiency, enabling scholarly communication and discovery, and aiding researchers in their work. Consequently, AGU Publications is taking steps to help our community adopt them.

Last month, AGU joined with about a dozen other publishers in a commitment to include the ORCID (Open Researcher and Contributor ID) for authors of all papers published in 2016 (see http://bit.ly/ORCID-commitment).

Using ORCID

ORCID provides an important means for improving discoverability and recognition for researchers. They create their own ORCIDs through simple registration, and they fully control the privacy of their accounts. Authors and reviewers can easily create an ORCID or link to it in AGU's editorial system, GEMS.

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Most publishers, including AGU, require that grant information be included in published papers. Now that CrossRef offers an open registry of funders known as FundRef, AGU collects this information in our editorial system as FundRef identifiers (see http://bit.ly/FundRef). This enables funders to accurately identify outcomes of grants. It also enables public access to published papers funded by participants registered through CHORUS. For the geosciences, participating funders include the National Science Foundation, the U.S. Geological Survey, and the U.S. Department of Energy, among others.

Publishers Can't Do It Alone This Time

Although the first generation of identifiers, such as DOIs, could be registered and administered entirely by publishers, we need your help to enable and empower newer identifiers, such as ORCID, IGSNs, and FundRef. We appreciate that creating and linking or entering more identifiers can represent additional work and effort by scholars, adding to an already complex process. In some cases, however, these open community identifiers can replace other information or can streamline entry, simplify processes, or eliminate work later.

The potential benefits from widespread adoption of all these identifiers, as seen already for DOIs, are great, including fostering discovery and management elsewhere. AGU is committed to using technology to simplify other parts of the submission and review process as much as possible.

Further details about these identifiers are available at URLs listed above.

By **Brooks Hanson,** Director of Publications, AGU; email: bhanson@agu.org

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Hawaii's Swelling Lava Lake Charts a Volcano's Hidden Plumbing

USGS

The "Overlook crater" near the summit of Kilauea Volcano hosts one of the largest lava lakes in the world (shown here). Recent research sheds light on gas-pistoning activity that may have contributed to the dramatic rise and fall of lava columns connected to the crater.

It's been 7 years since an explosive eruption left a massive hole in Halemaʻumaʻu crater, just below an overlook point at the summit of Kilauea Volcano in Hawaiʻi Volcanoes National Park. As the surrounding walls have collapsed, the "Overlook crater" has grown from just 35 to more than 200 meters wide and now hosts an impressive lava lake. Scientists suspect the lava lake's depth, estimated at around 200 meters, makes it among the largest in the world.

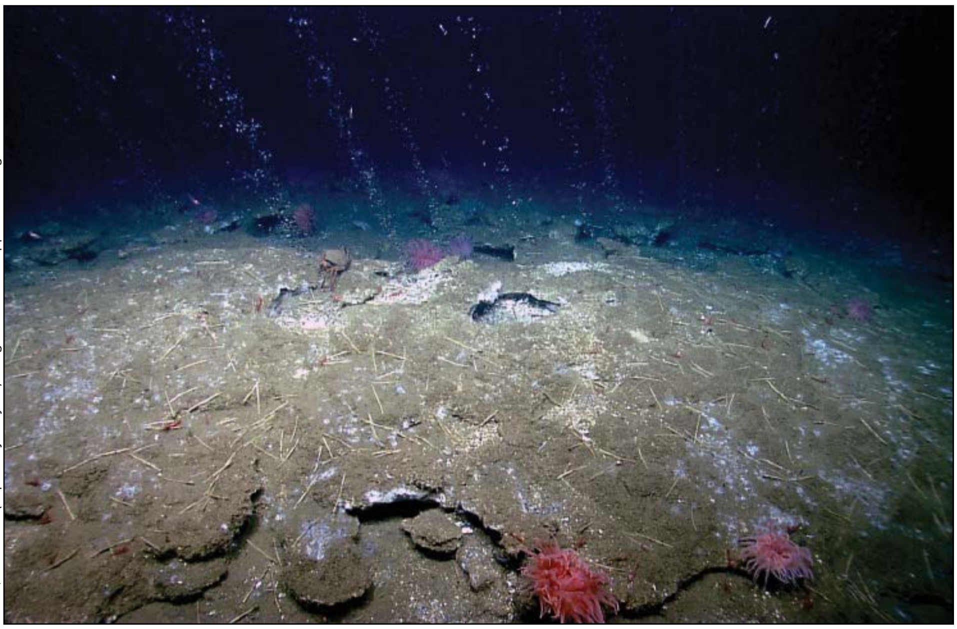
The action has been monitored by a network of Hawaiian Volcano Observatory seismometers, which allowed *Chouet and Dawson* to track tremors originating from a kilometer below the surface. Before the lake formed, the instruments caught degassing bursts from the top of the lava column. Since then, much of the seismic activity can be explained by rockfalls as the crater grows. A third type of activity is more puzzling, consisting of unusual pressure drops from somewhere within the magma system but with no signs of disturbance on the lake's surface.

The authors focused their efforts on a fourth type of activity known as gas pistoning, in which the lava column sees a cyclic approximately 20-minute-long rise and fall of its thinly crusted surface. Geologists say the activity is caused by the accumulation of gas in a layer of foam at the top of the column before it's released—often forcefully when the foam collapses.

The pair tracked the signature to a single point source that sits 1 kilometer below Halemaʻumaʻu crater's eastern flank. The seismic waves also map out the volcano's plumbing system, which consists of pipes, dikes, and fissures beneath the park that correspond well to previous attempts to chart the underground network.

Using numerical simulations, the researchers calculated that layers of foam in the lava column—perhaps tens of meters high—grew and collapsed in hundreds of gas piston events during one well-documented 5-day period in the summer of 2011. The gas-pistoning activity likely happened in a 6-meter-wide pipe that connected the crater to an adjacent dike system. This study is central to determining the behavior of the magmatic system beneath Halemaʻumaʻu and volcanic systems in general, protecting communities in Hawaii and around the world. (*Journal of Geophysical Research: Solid Earth*, doi:10.1002/2014JB011789, 2015) **—Eric Betz, Freelance Writer**

Rising Temperatures Release Methane Locked in the Seabed



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Methane-metabolizing bacteria in seawater prevent the majority of the gas released from seeps like this one off the coast of Virginia from making it to the atmosphere.

Methane is a potent greenhouse gas that comes from a variety of natural sources, including the shallow seafloor sediment along continental margins—where the thick continental crust rapidly slopes down into the thin oceanic crust. These shallow marine sediment reservoirs include permafrost and methane hydrate, an icy solid that forms when high pressure and low temperatures force water molecules to form a crystalline cage around methane. When temperatures rise or pressure decreases, hydrates melt and release methane into seafloor sediments; from there it can make its way into the air. Since methane traps solar radiation in the atmosphere even more efficiently than carbon dioxide, these concentrated methane-filled snowballs can have a powerful effect on Earth's climate.

Here *Graves et al.* assess how methane released at the seafloor makes it into the surface water and its potential role in climate warming. The team measured methane levels in seawater near the gas hydrate stability zone off the shore of the Svalbard Islands in Norway, where gas hydrates form naturally in the seabed. They used sonar to locate the bubble plumes that indicate methane seepage, which occurs at approximately 400 meters water depth, and took samples throughout the water column and surrounding air in this area. The team used these data to calculate the concentrations of dissolved methane in the upper slope and shelf region of the islands.

The researchers found that methane levels were highest close to the seabed but that roughly 60% of the methane leaving the seafloor was oxidized before it had a chance to merge with surface waters. Oxidation carried out by aerobic methanotrophs—bacteria that metabolize methane—is the dominant process (as opposed to dilution, where methane concentrations decrease through water mixing). Because of this, the exchange of methane between the sea surface waters and the air remained relatively low. Using these findings, the team concluded that methane released into the atmosphere comes mainly from the shallower areas of the shelf, where it has a better chance of reaching the surface without being oxidized.

Understanding the interactions between oceanic methane systems and the atmosphere will only become more critical in the future, as rising global temperatures increase the melting rate of methane hydrates. (*Journal of Geophysical Research: Oceans*, doi:10.1002/2015JC011084, 2015) **—Lily Strelich, Freelance Writer**

Sea Surface Temperatures on the Rise in the Caribbean

The elegant chaos of Earth's oceans drives a complex system of exchanges, as landmasses and bodies of water trade heat, moisture, and energy with the atmosphere. These interactions, and the changes in global climate that drive them, are manifested in variations of temperature along the ocean's surface.

Sea surface temperature offers insight into the behavior of climatological phenomena like convection cells, tropical storms and hurricanes, and prevailing winds. These mechanisms converge in the Intra-Americas Region (IAR), which includes the Caribbean, Mexico, Central America, and parts of North and South America.

The region is also home to phenomena like the midsummer drought and the Atlantic Warm Pool, which work in conjunction with small-scale mechanisms to transport moisture—and storms—to North America. This vital function makes the IAR particularly sensitive to changes in climate. Determining how climate change affects the IAR is crucial to understanding how global temperature changes will manifest locally.

Scientists with the National Oceanic and Atmospheric Administration (NOAA) and the NOAA Cooperative and Remote Sensing Science and Technology Center at the City College of New York studied sea surface temperature in an effort to clarify its importance in IAR climate dynamics. *Glenn et al.* examined high-resolution satellite data collected between 1982 and 2012 and observed an overall warming trend, with the most significant increase occurring over the past 15 years. Warming was greatest in the Gulf of Mexico, just north of South America, and appeared to coincide with large-scale phenomena like the El Niño–Southern Oscillation and the early and late Caribbean rainy seasons.

Such trends point to the correlation between sea surface temperature and large-scale processes—a symbiotic relationship that drives the global climate. The IAR is complicated, but a systematic approach will help scientists build a more precise picture of the climate mechanisms that affect infrastructure, economies, and lives. (*Geophysical Research Letters*, doi:10.1002/2015GL065002, 2015) **—Lily Strelich, Freelance Writer**

Climate Variability Across Scales Affects Ecosystems over Time

Century-scale temperature changes and record-breaking storms may grab headlines, but variations in climate are manifested in diverse ways across time and around the globe. Changing patterns in temperature, precipitation, and solar radiation have profound effects on local ecosystem functioning, and scientists are still working to better codify the complex interactions between meteorological variability and the movement of water and carbon through those ecosystems, also known as "fluxes."

Vegetation plays a vital role in this transport of water and carbon, and changes in climate have a profound impact on where and how plants grow, as measured by variability of biomass over time scales much longer than the short-term meteorological drivers. These variations, in turn, influence global climate via biomass coverage, hydrologic variability, and carbon cycling. Thus, identifying how small-scale meteorological changes affect local biological, hydrological, and ecological processes is fundamental to improving climate mitigation and resource management.

Simone Fatichi

Vegetation plays a vital role in the transport of water and carbon. Changes in climate have a profound impact on where and how plants grow.

Climate variability on short time scales—hours to days—changes the energy balance of ecosystems, from boreal forests to semiarid shrublands. *Paschalis et al.* modeled interactions between soil, vegetation, and the atmosphere to measure these variations in energy and identify how environmental variations affect water and carbon fluxes. The team manipulated data from six distinct biomes across three continents with the mechanistic ecohydrological model Tethys-Chloris. They focused on distinguishing between how fluxes responded to environmental variables on different scales, from hours to years.

The scientists found that when short-term meteorological variables, like changes in air temperature over the course of a day, influenced short-term ecological processes like photosynthesis, the overall impact on water and carbon fluxes was small. The effects of short-term meteorological variations on long-term hydrological and ecological processes were more enduring.

For example, a short temporal scale can affect the movement and storage of water in the soil over a time scale stretched to a year or more. An ecosystem's response also depends on the limiting resource—precipitation drives annual-scale changes in arid regions, and temperature constrains biochemical processes that enable plants to assimilate carbon in cold regions.

Ultimately, meteorological variability on short time scales has a range of effects on the time-integrated water and carbon fluxes, with real ramifications for food production, resource management, and public health. (*Journal of Geophysical Research: Biogeosciences,* doi:10.1002/2015JG003002, 2015) **—Lily Strelich, Freelance Writer**

The Coming Blue Revolution

Human civilizations have always sprouted up around bodies of water. We've created increasingly efficient infrastructures to harness and store the precious resource, reaching a scale so enormous that human activities now have a substantial impact on the global water cycle. *Kumar* provides a framework to integrate cross-disciplinary approaches to water scarcity in order to reveal innovative, holistic solutions.

The water cycle is intimately linked with Earth's carbon, nutrient, and energy cycles—all of which have been greatly impacted by human activities. The complexity of these interconnected systems ensures that any perturbation—for example, a forest fire, a catastrophic flood, or an extended drought—will have unpredictable consequences as it propagates through each cycle. Because these emergent responses are nearly impossible to plan for or protect against, they pose a great threat to humans.

The author explains that scientists are asked to address problems that are complex and messy because no clear pathways toward solutions may exist. Further, multiple solutions may present equally satisfying or unsatisfying outcomes. His integrated framework of the water cycle and humanity's place in it, which he calls "hydrocomplexity," aims to identify the best practices for addressing emergent threats against water security that come from climate change, increasing reliance on limited resources, and intensive land management and development.

The author argues that to model how perturbations will propagate through the water, carbon, and nutrient cycles and generate various emergent responses, scientists need a comprehensive understanding of the processes at play in each of the interconnected cycles.

He also suggests that hydrologic patterns will likely be revealed through the integration of models with a rapidly growing body of diverse observational records by computational systems that crunch large volumes of data.

Tim J Keegan, CC BY-SA 2.0 (http://bit.ly/ccbysa2-0)

The dry lakebed visible at Australia's Lake Hume is a stark reminder that water scarcity is one of modern societies' most pressing challenges.

Finally, understanding how information flows through institutional networks and triggers human action will also provide insights toward developing effective solutions to water scarcity that people will actually adopt.

Already, much of the world is dealing with an extreme and chronic shortage of freshwater; essentially, humans are using the resource faster than it can be replenished by the normal hydrologic cycle. The underlying idea of the author's framework is that understanding our role in the complex water cycle is the first step toward managing inevitable water security challenges of the future. (*Water Resources Research,* doi:10.1002/2015WR017342, 2015) **—Kate Wheeling, Freelance Writer**

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Hydrology

Tenure-Track Assistant Professor Position GROUNDWATER HYDROLOGIST University of Wyoming

The Department of Civil and Architectural Engineering at the University of Wyoming invites applications for a tenure-track faculty position in Groundwater Hydrology at the Assistant Professor level. We seek a candidate with the interest and abilit y to develop and sustain a nationally competitive research program. The successful candidate must hold an earned doctoral degree in Civil Engineering or in a closely related discipline by the position start date. Registration as a professional engineer or professional hydrologist are desirable but not required. The successful candidate must be able to teach courses in fluid mechanics, hydraulics, hydrology, and water resources engineering. Also, the successful candidate must have the demonstrated ability to develop an externally funded research program in groundwater hydrology.

This position will become part of a major research thrust in water resources at the University of Wyoming. Groundwater resources are of immense impo11ance to societal and ecological needs. Approximately half of Wyoming water resources are from groundwater, and subsurface resources provide critical water to agriculture, oil and gas development, and municipalities. There are tremendous research challenges in groundwater resulting from changing climate signals and human population patterns, and emerging techniques provide outstanding opportunities for groundwater hydrologists to better quantify the fate and transport of water in a changing west. We seek a groundwater hydrologist with experience in laboratory and field approaches for describing complex subsurface processes. Areas of specific interest include, but are not limited to, surface-groundwater interaction, unsaturated flow and contaminant transport.

As a member of the faculty of the Department of Civil and Architectural Engineering, the successful candidate will integrate his or her research with the goals of the new Wyoming Center for Environmental Hydrology and Geophysics (http://www.uwyo.edu/epscor/wycehg/) and provide academic support to the PhD program in Water Resources, Environmental Science and Engineering (http://www.uwyo.edu/wrese/).

UW faculty have access to world-class computational resources as described at: https://arcc.uwyo.edu/. The depatiment is supported by 22 tenured or tenure-track faculty and offers ABET-accredited baccalaureate programs in both civil engineering and architectural engineering to approximately 300 undergraduate students. The department also offers graduate

programs at the Masters and PhD levels to roughly 60 graduate students.

Laramie is a picturesque and friendly town offering a reasonable cost of living, good K-12 public schools and easy access to outdoor activities in the Rocky Mountain region. Additional information on the Department, College, and Laramie is available at: http://www.uwyo.edu/civil , http://ceas.uwyo.edu and http://www.laramie.org.

Applications must include: 1) a letter of application, 2) a curriculum vitae including a list of publications, 3) a statement of research interests, 4) a statement ofteaching interests, and 5) contact information for at least three references. Do not include supplemental information such as off-prints of papers, reference letters, or transcripts. Review of applications will begin 15 September 2015 and continue until the position is filled. The preferred start date for the position is January 2016. Submit applications in a single PDF file to: water_search@uwyo.edu.

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Student Opportunities

Graduate Research Assistantship (PhD) in Remote Sensing Ecosystem Science

The Department of Geosciences at Boise State University currently has an open graduate research assistantship (GRA) starting summer or fall 2016 to study the response of northern peatland ecosystems to increased temperature and elevated atmospheric CO2 with remote sensing. This project is supported by DOE's SPRUCE experiment. Please see here for more details: http://bcal.boisestate.edu/blog/phd-assistantship-available/

PhD Fellowships in Remote Sensing are available immediately in Virginia Tech's Interdisciplinary Graduate Program.

Remote Sensing is an interdisciplinary field which is evolving rapidly to address a wide range of scientific and societal problems. Virginia Tech's Remote Sensing graduate program spans nine departments in five separate colleges and covers all aspects of Remote Sensing, including engineering, theory, data analysis, applications, and policy. Students in the program pursue a Ph.D. in a core discipline in their home department while taking additional interdisciplinary courses which count toward a Remote Sensing Certificate. Interested applicants are encouraged to visit our website (http://rsigep.frec.vt.edu/) to learn more about the curriculum, specific research themes, the application process, and how to communicate with prospective advisors. General questions can be directed to rs_igep@vt.edu.

PhD research opportunity (stipend+-tuition), Department of Earth and Environmental Studies, Montclair State University.

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Postcards from the Field

As part of a project that aims to improve the crustal velocity model along the St. Lawrence River, four telemetered broadband seismographs have been deployed by the Geological Survey of Canada (GSC) between the Charlevoix Seismic Zone and the Lower St. Lawrence Seismic Zones of Quebec, Canada. The photo shows one of these installations where the Saguenay meets the St. Lawrence River (the town of Tadoussac is seen in the background). The GSC technologist Calvin Andrews is shown making the last checks to the electronic box that contains the digitizer, the GPS antenna, the AC/DC converter, and the cell phone antenna. The seismometer is protected by the seismic vault that lies directly on the Canadian Shield bedrock (black cylinder with cable at the lower left).

—**Maurice Lamontagne,**
Seismologist,
Geological Survey of Canada, Ottawa

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